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of

THE ROYAL AERONAUTICAL SOCIETY

MAY 1960

CONTENTS

THE PRESIDENT, 1960-61—Dr. E. S. MOULT, C.B.E., B.Sc.(Eng.), F.R.Ae.S., M.I.Mech.E.

NOTICES

CURRENT PROBLEMS IN AERO ENGINE DESIGN—THE THIRTEENTH LOUIS BLÉRIOT LECTURE — DR. E. S. MOULT

DECK LANDING — LT. CDR. A. I. R. SHAW

THE AUSTRALIAN SOUNDING ROCKETS LONG TOM AND AEOLUS — D. A. H. BIRD

TECHNICAL NOTES

A Note on the Induced Drag of Jet-Flapped Wings—G. K. KORBACHER and K. SRIDHAR. A Simplified Method for Estimating the Properties of Thin Aerofoils Influenced By Jet—SVETOPOLK PIVKO. Elementary Stress Analysis of Circular Frames in a Cylinder Partially Filled with Fluid—A. R. HALLIWELL. Buckling of Unstiffened Shear Webs with Flanged Lightening Holes—Maureen E. MICHAEL. Probing Interplanetary Space—S. W. GREENWOOD.

THE BRANCHES

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INCORPORATING THE INSTITUTION OF AERONAUTICAL ENGINEERS AND THE HELICOPTER ASSOCIATION OF GREAT BRITAIN

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CONTENTS

		PAGE
The President, 1960-61—Dr. E. S. MOULT, C.B.E., B.Sc.(Eng.), F.R.Ae.S., M.I.Mech.E.		XXIII
Notices		XXV
Ninety-Fifth Annual Report of the Council—Whitsuntide Holiday—Historical Lecture by Sir Thomas Sopwith—The Forty-Eighth Wilbur Wright Memorial Lecture—The Society's Historical Collection—Honours Awarded to Members—Associate Fellowship Examination, June 1960—Agricultural Aviation Group—Rotorcraft Section Garden Party—Diary—Centenary Meeting of the Royal Institution of Naval Architects—Hunt for Battle of Britain Veterans—News of Members—Elections—Fourth Congrès Aéronautique Européen—Royal Society of Arts Endowed Prizes—Changes of Address and Appointment—Journal Binding—Lecture Summaries.		
Current Problems in Aero Engine Design—The Thirteenth Louis Blériot Lecture	DR. E. S. MOULT	259
Deck Landing	LT. CDR. A. I. R. SHAW	273
The Australian Sounding Rockets Long Tom and Aeolus	D. A. H. BIRD	277
Technical Notes		290
A Note on the Induced Drag of Jet-Flapped Wings—G. K. KORBACHER and K. SRIDHAR. A Simplified Method for Estimating the Properties of Thin Aerofoils Influenced By Jet—SVETOPOLK PIVKO. Elementary Stress Analysis of Circular Frames in a Cylinder Partially Filled with Fluid—A. R. HALLIWELL. Buckling of Unstiffened Shear Webs with Flanged Lightening Holes—MAUREEN E. MICHAEL. Probing Interplanetary Space—S. W. GREENWOOD.		
The Branches		302
Graduates' and Students' Section		303
The Library		304
REVIEWS: Satellites and Scientific Research—The New Frontier—Theoretical Elasticity—The Crowded Sky—Available Energy and the Second Law Analysis—Similarity and Dimensional Methods in Mechanics—Introduction to the Theory of Compressible Flow—New Zealanders with the Royal Air Force—A Textbook of Fluid Mechanics for Engineering Students—Famous Bombers of the Second World War.		
ADDITIONS TO THE LIBRARY REPORTS		

All communications for publication in the JOURNAL *should be addressed to the Editor,* JOAN BRADBROOKE, *A.R.Ae.S.; all communications on general matters affecting the Society should be addressed to the Secretary,* A. M. BALLANTYNE, *T.D., B.Sc., Ph.D., F.R.Ae.S., Hon.F.C.A.I., F.I.A.S.*

None of the papers or paragraphs must be taken as expressing the opinion of the Council of the Royal Aeronautical Society unless otherwise stated.

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The President 1960-1961

E. S. MOULT, C.B.E., B.Sc.(Eng.), Ph.D., M.I.Mech.E., *Fellow*

DR. MOULT was born at Hucknall, Nottinghamshire, in 1903 and educated at Nottingham High School and University, taking an Honours Degree in Engineering in London in 1925. He then became an Engineering Student with Peter Hooker Ltd., Walthamstow, and had practical experience with both the Gnome and Le Rhone Engine Co., and the Newall Engineering Co.

Later, Dr. Moult joined Major Frank B. Halford—who was then in business on his own—as Technical Assistant and was concerned with the design and development of various de Havilland engines and with the 16-cylinder double crankshaft engine that later became the Napier Rapier. This liaison with Napier continued for over 15 years during which time the Rapier, Dagger and Sabre engines were evolved.

In 1941, still with Major Halford, Dr. Moult joined The de Havilland Aircraft Co. Ltd. and was appointed Chief Engineer of the Engineering Departments of the Engine and Propeller Divisions and was responsible for engine and propeller developments during the war years. Work on gas turbines was started in 1941 with the H.1 engine, which later became known as the Goblin and was the first jet engine to receive official Type Approval.

In 1944 The de Havilland Engine Company was formed as a separate entity and Dr. Moult was appointed Chief Engineer of all its various activities, which included piston engines, gas turbines and rocket motors.

He was appointed a Director of the Company in 1955 and Technical Director in 1957.

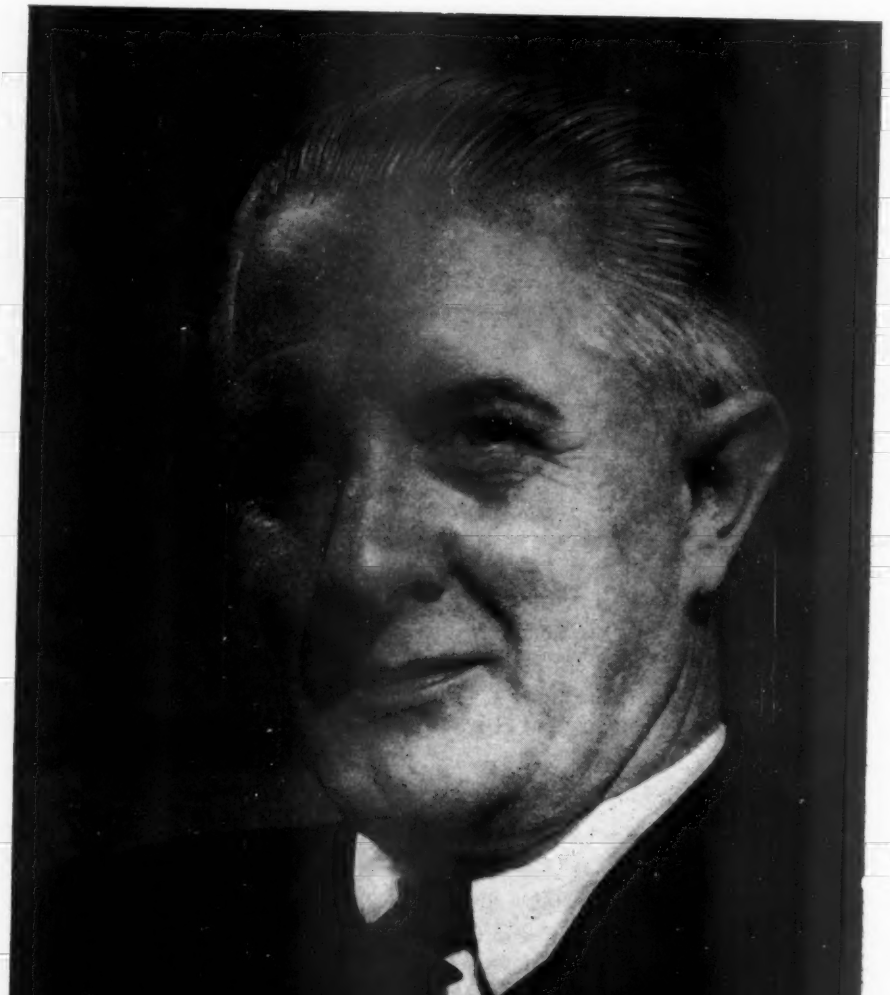
Dr. Moult has been a member of Council of the Society since 1951 and a Vice-President since 1956. For a number of years he was Chairman of the Grading Committee and he has served on various other Committees of the Society.

Since 1956 he has also been a member of Council of the Institution of Mechanical Engineers and in addition is a member of Council of the Automobile Division.

He has served on the Propulsion Committee of the Aeronautical Research Council and has been a member of the Gas Turbine Collaboration Committee since its formation in 1941.

He was awarded a C.B.E. in the Birthday Honours List in 1958.

Dr. Moult takes office on 5th May 1960 at the Annual General Meeting of the Society.



E. S. MOULT, C.B.E., B.Sc.(Eng.), Ph.D., M.I.Mech.E., *Fellow*

President 1960-1961

NOTICES

95TH ANNUAL REPORT OF THE COUNCIL

There were, unfortunately, two omissions from the 95th Annual Report of the Council published in the April JOURNAL. On *Representatives on Other Bodies* (p. 251) the following should have been included:—

Joint Committees for the Award of Higher National Certificates and Diplomas in Aeronautical Engineering in England, Wales and Northern Ireland—

Professor A. R. Collar — Mr. H. H. Gardner
Air Commodore J. R. Morgan — Dr. A. M. Ballantyne

On *Committees of Council*, it is regretted that Mr. P. W. Brooks' name was omitted from the *Historical Group Committee* (p. 251). He has been an active member of the Committee since the Group was formed.

THE SOCIETY'S HISTORICAL COLLECTION

The work being carried out by the Historic Aircraft Maintenance Group at the B.E.A. Engineering Base at London Airport is spread among ten teams. Each aircraft has its own team with a Leader and Deputy Leader taking charge of the work under the overall supervision of the Chief Engineer, Mr. A. S. Hughes. Recently a new team was formed which is undertaking the overhaul and re-furbishing of the engines in the Collection. The core of this valuable assembly is of course the Nash Collection of Veteran Aircraft. From time to time, additional items are presented to the Society and are added to the Collection. The most recent is the beautifully restored Viale engine which has been presented by two members of the Bristol Branch. This five-cylinder radial dates from 1910 and the gift to the Society is most gratefully acknowledged.

It is hoped that work on the Military Avro 504K will be finished within the next two months. The repairs to the Blériot XXVII are also going ahead well and should be completed this summer. Once these aircraft are finished, the teams can tackle other items in the Collection. The available manpower is therefore distributed so as to produce results as quickly as possible from those aircraft which are most easily dealt with.

Now that the finishing stages are in sight the Society has been fortunate in obtaining the help of two highly qualified specialists who have accepted invitations to advise the Group on dates of construction and colours and markings appropriate to those dates. Mr. C. Rupert Moore, A.R.C.A., the aeronautical artist has, for many years, painstakingly been compiling a record of actual aircraft colours and finishes by taking samples and matching them. These samples range from pre-1914 to the present day. Mr. Moore has agreed to act as Art Adviser to the Group and has already prepared samples of colours to be made up for several of the aircraft. These samples have been matched exactly from specimens of colours obtained over forty years ago.

Historical accuracy is of vital importance in this work of restoration and Mr. J. M. Bruce, the authority on aeroplanes of the First World War, is advising on the origins and serial numbers of such aircraft as the Sopwith Camel and the S.E.5A and has kindly made information available from his extensive records. Mr. Bruce is a member of the Steering Committee of the Historical Group.

The Society greatly appreciates the help given by so many people who devote a great deal of their time and knowledge to the restoration of this valuable collection.

A view of the Society's aircraft in the B.E.A. hangar. In the foreground the military Avro 504K, and in the background one of B.E.A.'s Comet 4Bs.
(Courtesy of B.O.A.C. Gazette)

WHITSUNTIDE HOLIDAY

The Offices of the Society will be closed from Friday afternoon, 3rd June until Tuesday 7th June 1960.

HISTORICAL LECTURE BY SIR THOMAS SOPWITH

Sir Thomas Sopwith, C.B.E., *Honorary Fellow*, will give the first lecture to the Historical Group of the Society, on "My First Ten Years," on Tuesday 17th May 1960 at the Institution of Mechanical Engineers, 1 Birdcage Walk, London S.W.1, at 6 p.m. Mr. Peter G. Masefield, M.A., F.R.Ae.S., Hon.F.I.A.S., M.Inst.T., Past President, will take the Chair.

Visitors tickets may be obtained from the Secretary. Members of the Society do not require tickets.

THE FORTY-EIGHTH WILBUR WRIGHT MEMORIAL LECTURE

The Forty-Eighth Wilbur Wright Memorial Lecture will be given at the Institution of Mechanical Engineers, Birdcage Walk, S.W.1, on Thursday 19th May 1960 at 6 p.m. (Tea at 5.30 p.m.), by Mr. M. J. Lighthill, F.R.S., Director of the Royal Aircraft Establishment, on "Mathematics and Aeronautics."

ASSOCIATE FELLOWSHIP EXAMINATION, JUNE 1960

The Associate Fellowship Examination will be held on 21st, 22nd and 23rd June 1960. The time-table will be sent to all candidates.

HONOURS AWARDED TO MEMBERS

Professor J. A. J. Bennett (*Fellow*) has been awarded the Breguet Memorial Trophy for 1959 (awarded Annually by the Royal Aero Club for meritorious achievement in the development of VTOL aircraft) "for his exceptional technical contributions over the years to the rotary-wing art, and in particular for his basic conception of the principles embodied in compound rotor craft with fixed wings and propellers."

Sir Harry Ricardo (*Fellow*) has received an Honorary Degree from Turin Polytechnic School.

AGRICULTURAL AVIATION GROUP

The First Annual General Meeting of the Agricultural Aviation Group of the Society will be held on Wednesday, 25th May 1960 at 7.30 p.m. at 4 Hamilton Place.

ROTORCRAFT SECTION GARDEN PARTY

The Helicopter Rally and Garden Party, formerly an annual function of the Helicopter Association of Great Britain, will be held this year by the Rotorcraft Section of the Society on Saturday, 11th June. Mr. and Mrs. Charles Hughesdon have again generously offered the use of their beautiful grounds at Ripley, Surrey.

Attendance will be by invitation only.

DIARY

LONDON

19th May

FORTY-EIGHTH WILBUR WRIGHT MEMORIAL LECTURE—Mathematics and Aeronautics. M. J. Lighthill. The Institution of Mechanical Engineers, Birdcage Walk, S.W.1. 6 p.m. (Tea 5.30 p.m.)

ASTRONAUTICS AND GUIDED FLIGHT SECTION

12th May

On Reducing Costs of Space Research. J. E. Allen. Institution of Mechanical Engineers, Birdcage Walk, S.W.1. 6 p.m. (Tea 5.30 p.m.)

ROTORCRAFT SECTION

10th June

Helicopter Vibration. Dr. J. P. Jones. Library, 4 Hamilton Place. 6 p.m.

HISTORICAL GROUP

17th May

My First Ten Years. Sir Thomas Sopwith, C.B.E. At the Institution of Mechanical Engineers, Birdcage Walk, S.W.1. 6 p.m. (Tea at 5.30 p.m.)

BRANCHES

11th May

Chester—Annual General Meeting and Film Show. Lecture Theatre, Grosvenor Museum. 7.30 p.m.

Hatfield—Second Halford Lecture—Power Plants for Supersonic Transports. J. S. Alford. Hatfield Technical College. 6.30 p.m.

20th May

Birmingham and Wolverhampton—Annual General Meeting. Wolverhampton. 7.30 p.m.

25th May

Hatfield—Annual General Meeting. de Havilland Restaurant. 6.15 p.m.

CENTENARY MEETING OF THE ROYAL INSTITUTION OF NAVAL ARCHITECTS

Members of the Society are invited to attend The Opening Ceremony and reading of papers on the occasion of the Institution's Centenary Meeting at the Royal Festival Hall on 17th May at 2.30 p.m.

His Royal Highness Prince Philip, Duke of Edinburgh (Honorary Member) will open the Proceedings. The following two papers will be read:—

"Warships, 1860-1960" by A. J. Sims, O.B.E., R.C.N.C.

"Merchant Ships, 1860-1960" by J. M. Murray, M.B.E., B.Sc.

Visitors, who may be accompanied by a lady, must be seated by 2.15 p.m. Admission cards may be obtained from The Secretary of the Institution, 10 Upper Belgrave Street, London S.W.1.

HUNT FOR BATTLE OF BRITAIN VETERANS

The Battle of Britain Fighter Association, formed in 1958, draws its membership from "The Few" and past and present members of the R.A.F. and Commonwealth and Allied Air Forces entitled to wear the Battle of Britain clasp to the 1939-45 Star.

In this, the year of the 20th anniversary of the Battle of Britain, the Association wants to trace about 150 ex-R.A.F. air crew members who, although entitled to wear the Battle of Britain clasp, are not members of the Association.

Those entitled to wear the clasp who are not members of the Association are invited to write to the Secretary, Air Ministry (Room 0211), Whitehall, London S.W.1.

NEWS OF MEMBERS

Sqn. Ldr. R. W. BRAY (*Associate*) formerly at R.A.F. Hornchurch, is now in Command of the Blind Landing Experimental Unit, R.A.E., Bedford.

ERIC B. CARTER (*Associate Fellow*) formerly in the Directorate of Engineering Research and Development, is now Director of Engine Production, Ministry of Aviation.

P. B. CLAY (*Graduate*) formerly Overhaul Engineer with Rolls-Royce of Canada Ltd., has been transferred to Derby in the Service Organisation.

P. J. DUNCTON (*Associate Fellow*) Technical Manager (Atomics) Fairey Aviation Ltd., Heston, has been appointed Director and General Manager, Fairey Engineering Limited.

B. C. DUTTA (*Associate Fellow*) formerly with Hindustan Aircraft Ltd., Bangalore, is now Senior Scientific Officer, with the Directorate of Technical Development and Production (Air) at the Ministry of Defence (Gas Turbine Research Centre).

L. G. FAIRHURST (*Fellow*) formerly Technical Director and Chief Engineer, Rotol Ltd., is now Technical Director, Dowty Rotol Ltd.

P. G. FIELDING (*Associate Fellow*) formerly a Project Engineer at the Lockheed Aircraft Corporation, Special Devices Division, is now Project Director (Aviation) in the Transportation Research Office of Booz, Allen Applied Research, Inc., Maryland.

P. A. HEARNE (*Associate Fellow*) formerly Divisional Manager of the Guided Weapons Division, Elliott Brothers (London) Ltd., is now Assistant General Manager of the Guided Flight Group of Divisions of that Company.

B. J. HOLMES (*Associate*) formerly Designer in Charge of Drawing Office at the College of Aeronautics, is now a Senior Engineer with Richardsons and Westgarth Ltd., Newcastle-upon-Tyne.

L. R. I'ANSON (*Associate Fellow*) formerly a Senior Designer with the English Electric Aviation Co. Ltd., is now with Canadair Limited, Montreal as a Senior Thermodynamicist.

WING CDR. I. N. M. MACDONALD (*Associate Fellow*), formerly in the Department of the Chief of the Air Staff, Air Ministry, has retired from the R.A.F. and joined the Morgan Crucible Co. Ltd.

P. W. NORTON (*Associate*) formerly Technical Instructor, General Precision Systems Ltd., is now Technical Instructor, No. 1 School of Technical Training, R.A.F. Halton.

J. D. OLIVER (*Associate*) formerly Aircraft Artificer 2nd Class with the R.N. Fleet Air Arm, Manadon, is now a Rolls-Royce Representative at Boeing Airplane Co., Seattle, U.S.A.

G. K. C. PARDOE (*Graduate*) formerly an Aerodynamicist with de Havilland Propellers Ltd., London, is now Manager, Project Office.

J. J. PEARSON (*Associate Fellow*) formerly Senior Design Engineer, Republic Aviation Corporation, Long Island, N.Y., is now Chief Mechanical Designer, Plasma Propulsion Project, with the Company.

C. PIMLEY (*Associate*) formerly with Rheem Manufacturing, Defense and Technical Co. in California, is now a Stress Analyst for Hamilton Standard in Windsor Locks, Connecticut.

D. C. ROBERTS (*Graduate*) formerly a Technician, Armstrong Whitworth Aircraft Co. Ltd., is now taking the Post Graduate Course in Nuclear Engineering at Queen Mary College, University of London.

S. R. SARRAILHÉ (*Associate Fellow*) formerly Assistant Chief Stressman, Fairey Aviation Ltd., is now a Senior Stress Engineer, Vickers-Armstrongs (Aircraft) Ltd., Weybridge.

N. R. SPEDDINGS (*Graduate*) formerly in the Aerodynamics Department, Bristol Siddeley Engines Ltd., is now with the Aeronautical Research Laboratory, Armstrong Whitworth Aircraft Ltd., Whitley.

Sqn. Ldr. I. T. SUTHERLAND (*Graduate*) has been posted for Engineering Duties on the R.A.A.F. Staff at Australia House.

P. H. SWIFT (*Graduate*) formerly an Aerodynamicist, Vickers-Armstrongs (Aircraft) Ltd., Weybridge, is now an Aerodynamics Engineer with Aer Lingus, Dublin.

Sqn. Ldr. S. TIPPER (*Associate*) formerly Technical Officer, R.A.F. Tengah, Singapore, is now O.C. Engineer Support Squadron, R.A.F. Chippenham, Wilts.

E. TREES (*Associate*) formerly Aviation Manager, London Division of Shell-Mex and B.P. Ltd., is now Assistant Manager (Sales), Aviation Department.

A. J. WALLS (*Associate Fellow*) formerly Chief Development Engineer, Aer Lingus—Irish International Airlines—has been appointed Sales Manager.

R. G. B. WEBB (*Graduate*) formerly Technical Assistant (Wind Tunnels) with de Havilland Aircraft Ltd., Hatfield, is now on a Short Service Commission in the Technical Branch, R.A.F. Thetford, Norfolk.

C. J. WHITEHEAD (*Associate*) formerly with the Future Project Group (Armaments Division), Armstrong Whitworth Aircraft Ltd., is now Senior Mathematics Master, Beauchamp High School, Warwick.

A. A. J. WILLETT (*Associate Fellow*) formerly Chief Designer, Dowty Equipment Ltd., is now Chief Engineer, Arle Court Design Dept., Dowty Rotol Ltd.

M. L. WOODWARD (*Graduate*) is now a Development Engineer, Bristol Siddeley Engines Ltd., Coventry.

G. E. F. YOUNG (*Graduate*) formerly Repair Section, Drawing Office, de Havilland Aircraft Ltd., Hatfield, is now with Bennett Aviation, New Zealand.

ELECTIONS

The following is a list of elections and transfers of membership of the Society:—

Associate Fellows

Edgar Hubert Adams
Thomas Wilson Anderson
Aubrey Leonard Baker (*from Graduate*)
Fred Birchall (*from Graduate*)
Forester Richard John Britten
Michael John Broad (*from Graduate*)
Peter Graham Burden
David Chapman (*from Graduate*)
James Nelson Daniel
John Samuel Fay
Edward Fennessy
Charles Huron Kaman
Bartram Kelley
Philip C. Krause
Marcel Kretz
Haig Kurkjian
Donald Edward Lennard (*from Graduate*)
Gordon John Lewis
John Oliver Hargreaves Lobley (*from Associate*)
Alan Gordon MacGregor
William Arthur Mallinson
Donald N. Meyers
Rene Harcourt Miller
John Burton Nichols
Sanford F. Nicol
James Braddock Russell (*from Graduate*)
Wieslaw Z. Stepniewski
Alwyn Otley Sutcliffe
Arthur Brian Taylor (*from Graduate*)
John Derek Teare (*from Graduate*)
John Graham Theilmann
Michael John Theodore
Arthur Cornwallis Tomlinson
Kenneth Robin Warren (*ex Graduate*)
George Edward Whitmarsh (*from Graduate*)
Douglas Charles Franklin Williams (*from Graduate*)

Associates

Frank Barnes
Peter Charles Berryman
Nils Gustaf Erik Billing
Michael D. Buivid
J. Kenneth Graham
Alan George Green
Douglas Edward Green
Kenneth Arthur Hammer (*ex Student*)
Jack Davy Hayhow
Alexander Hyland
Francis John Lock (*from Student*)
James Macaskill
Desmond Maurice Massey-Shaw
Frank James Merson
Jack Douglas Mills
William Shanks Nelson
John Morton Paterson
James Bryan Shaw
Keith Edwin Sissons
David Alfred Thomas

Graduates

Patrick Ralph Ashill (*from Student*)
Alexander Christie
Anthony John Devereux
Ian Archibald Fisher (*from Student*)
Michael Keith Foster
Eliahod Israel Hay
Peter William Hyde (*from Student*)
Raymond Carey Morgan (*from Student*)
Henry Erick Tuisku North
Peter George Ryan (*from Student*)
Reginald Noel Shield (*from Student*)
James Craven Waddington (*from Student*)
Arthur Lawrence Webb (*from Student*)
Roger Edgar Whitbread (*from Student*)
Michael Christopher Whiteley

Students

Michael Archer
Harold William Cuckow
John William Charles McDaid
Roger Thomas Newby
Peter Geoffrey Porter
Anthony Sharpe
Stewart Michael Snowden
Michael John Tunstall
John Blyth Watson
Miriam Weller
Brian Woodason

Companions

Ralph Davison Blackett
Jim Marsh Darwin
Charles John Fooks
Lord Kindersley
William George Leslie
Theodore N. Pfeifer
Edward John Posey
Alfred L. Wolf

ROYAL SOCIETY OF ARTS ENDOWED PRIZES

The Royal Society of Arts offers the following prizes during 1960:—

The Howard Prize of £50 for Mechanical Motive Power will be awarded to the author of a treatise on some aspect of the subject of motive agents.

The Fothergill Prize of £20 for Fire Prevention or Fire-Fighting for a descriptive essay or model embodying some new idea for the prevention or suppression of fire.

Conditions of entry may be obtained from The Royal Society of Arts, John Adam Street, Adelphi, London W.C.2.

FOURTH CONGRÈS AÉRONAUTIQUE EUROPÉEN

The Fourth Congrès Aéronautique Européen, which is held in alternate years, will take place in Cologne from 18th-22nd September 1960.

Full particulars may be obtained from Herr Ennenbach, Secretary General, W. G. L., Eberplatz 2V, Cologne, Germany.

CHANGES OF ADDRESS OR APPOINTMENT

To assist in keeping the records of members correct and up to date the Secretary will be glad if all members will notify him as soon as possible of changes of address. He would also like to know of any change of appointment.

When notifying changes please give the following particulars:—

Name (in block letters) Grade of Membership
New Address (in block letters) Old address

New appointment.—Please give name and address of employer and position held.

Changes of address must be received *before the 15th of the month* in order to be effective for the following month's JOURNAL.

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Journals, with a note of the name and address of the sender, should be sent direct to The Lewes Press, Friars Walk, Lewes, Sussex, and the remittance to the Secretary at the Offices of the Society.

Members are asked to be certain that the address to which they want their Journals sent is the same on their letters to the Lewes Press and to the Society.

Lecture Summaries

Agricultural Aviation Group

PILOT TRAINING

Captain RICHARD BRADBURY and PETER AYLES

Given on 22nd April 1960

The methods of selection of inexperienced personnel who will eventually become agricultural pilots are outlined and a detailed list of the qualifications and characteristics necessary in this branch of aviation is given. Generally less than 10 per cent of applicants are found to be suitable.

The training programme is outlined in detail and the points to consider when converting a pilot to the kind of work which crop-spraying entails, is given.

Since there are so many different kinds of flying in the field of agricultural aviation, the additional training requirements are discussed in a general form, explaining the basic problems involved, the pitfalls, a run down on accidents caused through pilot error and the need for a thorough knowledge of the equipment used and the effect and reasons for the use of different chemicals. The authors also cover the following:—How a pilot is taught to tend to crops, to achieve the desired results, the "do's and don'ts" and common pilot faults in the early stages. The difficulties in keeping junior pilots within the law and emphasis on how instructions are given for the avoidance of damage to live stock. Converting fixed-wing pilots on to the helicopter, the training in brief and how this differs from crop spraying with the aeroplane.

The 48th Wilbur Wright Memorial Lecture

MATHEMATICS AND AERONAUTICS

M. J. LIGHTHILL, F.R.S.

To be given on 19th May

Aeronautics requires for its success the fusion of a multitude of different ways of thought, of which the mathematical way became one soon after the Wright Brothers' first experiments. The lecture surveys the major areas of aeronautics which are affected by mathematics: aerodynamics, including important work of early date on boundary layers, aerofoils and dynamic stability; elasticity, including static strength and aeroelastics; electromagnetic theory; servo-mechanisms. It distinguishes two modes of interaction—where the mathematics is used to generate (*i*) physical ideas (*ii*) numerical answers. The first mode remains the most strongly coupled, even though the second has gained from the introduction of high-speed computers.

After this broad survey, the lecture illustrates the points made by a general account of "slender-body theory," for high-speed or low-speed, unsteady or steady flow, with or without separation, and notes a variety of applications of this theory to aeronautics and other subjects.

Historical Group—Inaugural Lecture

MY FIRST TEN YEARS

Sir THOMAS SOPWITH, C.B.E., Hon.F.R.Ae.S.

To be given on 17th May

In this inaugural lecture to the Historical Group Sir Thomas recalls many of the people, places and events as he knew them in the years 1910-1921. He will describe how he first learned to fly, the first aeroplanes he owned and flew, the flight which won for him the de Forest Prize in 1910, some of the prize-winning flights in the pre-1914 days—and after; the beginning of the Sopwith Aviation Company, their first machines and some of those produced during 1914-18 up to the formation of the Hawker Engineering Company which it was intended should be a "small firm" and instead was the forerunner of today's Hawker Siddeley Group. The lecture will be illustrated by slides of many interesting aeroplanes—from the first one owned by Sir Thomas—the little Avis monoplane—to the first Hawker type—the Duiker.

Astronautics and Guided Flight Section

ON REDUCING COSTS OF SPACE RESEARCH

J. E. ALLEN, B.Sc., A.F.R.Ae.S.

To be given on 12th May

The objectives of space research now and in the future are outlined, and are considered in relation to specifications of vehicle performance. The several means of projecting scientific payloads into space, such as converted military ballistic missiles, large balloons and vehicles launched from aeroplanes are analysed. Technical trends towards cheaper fuels, less expensive research and development programmes and improvements in organisations are discussed. Future possibilities such as the alignment of aeronautical and astronautical programmes, solar sails and the economic returns which might be expected from space research will be touched upon.

Rotorcraft Section

THE PERSONAL HELICOPTER

J. S. SHAPIRO

Given on 6th May 1960

The lecture discusses the popular image of the helicopter as an aerial car and the need to distinguish between the helicopter as a symbol of vertical flight and as a mechanical contraption.

The lecturer's specification for the personal helicopter is that it should carry two to four people, including the pilot, be capable of flying in most weather conditions including zero visibility, icing conditions and in winds up to 50 m.p.h. It should have at least two engines so rated that flight or return to safety is possible on one engine. Special attention must be paid to safety; sealed maintenance of major assemblies is an essential condition and the helicopter must be easy to pilot with the dangers of over-speeding and stalling reliably excluded. Such a machine, with an acceptable noise level, if sold at the price of even a luxury car would have a large market. The author believes this prize has been within our grasp for some years without fundamentally new development.

The task of development requires not only a new effort but a new kind of framework, co-ordinating existing knowledge into a well-tuned machine.

The author discusses some of the current dogmas which beset the helicopter, such as "integrated lift systems," pipes versus gears, fatigue life, all of which divert effort and finance from the development of what is primarily a mechanical engineering device.

The limit for the concentration of small helicopters in the air is set, in the present state of knowledge, by air traffic control under poor visibility conditions.

Fundamentally new engineering conceptions and development of navigation approach and traffic control are needed before the helicopter can reach the million mark.

The author concludes with the belief that a small utility helicopter, sold at the price of a luxury car, even if it falls short of all the requirements of his specification, is the right measure of advance necessary to create a new industry.

The Journal of the Royal Aeronautical Society

INCORPORATING THE INSTITUTION OF AERONAUTICAL ENGINEERS AND THE HELICOPTER ASSOCIATION OF GREAT BRITAIN

VOLUME 64 MAY 1960 NUMBER 593

The Thirteenth Louis Bleriot Lecture

Current Problems in Aero Engine Design

by

E. S. MOULT, C.B.E., Ph.D., B.Sc.(Eng.), F.R.Ae.S., M.I.Mech.E.

(Technical Director, The de Havilland Engine Co. Ltd.)

The Thirteenth Louis Blériot Lecture was given in Paris on 2nd March 1960 under the auspices of L'Association Française des Ingénieurs et Techniciens de L'Aéronautique, by Dr. E. S. Moult, C.B.E., B.Sc.(Eng.), F.R.Ae.S., M.I.Mech.E., Technical Director of the de Havilland Engine Co. Ltd. and President-Elect of the Royal Aeronautical Society.

The Lecture was attended by Mr. Peter G. Masefield, M.A., F.R.Ae.S., Hon.F.I.A.S., M.Inst.T., President of the Society, Air Commodore F. R. Banks, C.B., O.B.E., C.G.I.A., F.R.Ae.S., Hon.F.I.A.S., M.I.Mech.E., Vice-President of the Society and the first Louis Blériot Lecturer, Dr. A. M. Ballantyne, T.D., B.Sc., F.R.Ae.S., Hon.F.C.A.I., A.F.I.A.S., and by other members of the Council and of the Aircraft Industry.

Monsieur Henri Potez, President of A.F.I.T.A., presided at the meeting, which was attended by a large and distinguished audience, including Madame Blériot. Mr. Masefield, speaking in French, expressed his pleasure and that of his colleagues, at being in Paris again for this re-union with their friends of A.F.I.T.A. and for this lecture in memory of that great pioneer of aeronautics, Louis Blériot. The President said that in the Royal Aeronautical Society they valued this occasion highly. With the Wilbur Wright Memorial Lecture, the Lanchester and the British Commonwealth Lectures, the Louis Blériot Lecture was always one of the highlights of their year. The President then introduced Dr. Moult.

Dr. Moult, also speaking in French, said that he did so with difficulty; because of this Monsieur Gospodarowicz had translated his paper and it would be read for him by Monsieur Vialatte and he was grateful to them both.

Introduction

I am deeply appreciative of the great honour you have bestowed upon me in asking me to address you tonight. When Louis Blériot made his memorable flight I was a boy of six and, I am sorry to say, not yet at school. In fact, I had to wait until I was nine to see my first aeroplane which, believe it or not, was a Blériot monoplane fitted with a Gnome engine and flown by another pioneer aviator, B. C. Hucks.

The simplicity of the aircraft and the apparent ease of flight made a deep impression on my boyish imagination. So much so that the same imagination was quite affronted when it first saw the pusher biplanes with which we prepared to fight the First World War. Having had nothing to do with it, I can now claim it took a further 25 years for the advancing march of aviation finally to confirm my childish fancy!

The engine of the aeroplane with which Louis Blériot made the first crossing of the Channel was a three-cylinder fan type Anzani. Many of the subsequent Blériot monoplanes were fitted with Gnome rotary engines. These were remarkable engines for their day and I had the good fortune to assist in their construction during my works' apprenticeship in the 1920s. Moreover, I am still working on the "Gnome" aero engine, although during the years it has rather changed its shape and multiplied its power tenfold. However, it is still a "rotary" in the best sense! (Fig. 1).

That, I regret to say, summarises my somewhat tenuous association with Monsieur Blériot and it is now my duty to proceed with the subject of this lecture. But, before we get involved in engines—their possibilities and their problems—it may be helpful to take a brief look at aviation today and the position in which we find ourselves.

The Post-War Situation

By the end of the Second World War, jet propulsion had demonstrated its potential and there followed a period of considerable activity while air forces were re-equipped, first with jet fighters and later with jet bombers. Because of the emphasis on military performance, the propeller-turbine was slow in arriving but, particularly in the civil field, it is now giving an excellent account of itself.

Civil transport by jet aircraft came with the Comet in 1952 and is now extending to first-class travel throughout the world.

Meanwhile, the military situation is overshadowed by the power of nuclear weapons and the new ways in

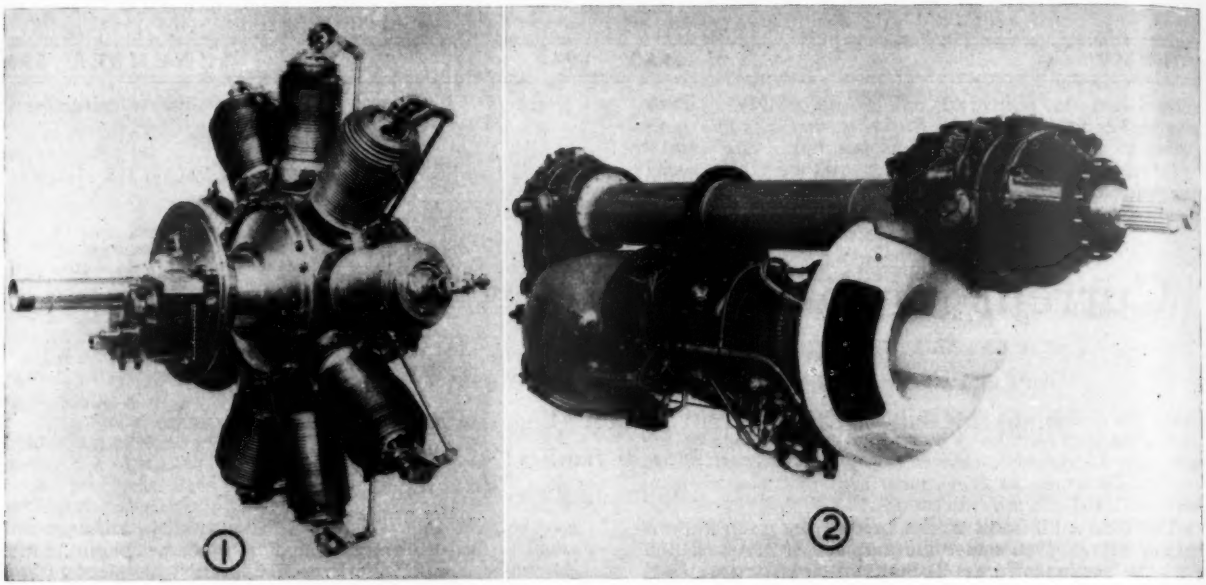

FIGURE 1. Gnome Rotary Engines. (1) Monosoupape. (2) Gnome Sans Soupape.

which they can be delivered: vast numbers of bombers and fighters are no longer required to meet a major threat. At the same time there is an obvious need for aircraft for local protection, for specialised purposes and for co-operation with land and sea forces. Above all, there is a need for rapid communication and transport over both short and long distances.

Present Trends

And now, having brought ourselves to the present, where are we going? It is always dangerous to prophesy, but it is necessary, at least, to have some philosophy on which to base our current thinking. In the military field, air-breathing engines already cover the speed range between zero Mach number in helicopters and over $M=2$ in the latest military aircraft. Missiles go at much higher speeds, propelled by rockets or ram-jets or combinations thereof.

The low-speed end of the speed scale is important because, not only do we have the continued development of the helicopter, but the coming of vertical lift by other means. At the present time there is great interest in aircraft capable of vertical or very short take-off and landing. In effect, these aircraft will give the advantages of the helicopter without the speed restrictions imposed by the conventional rotor. The military importance of vertical take-off for operation in forward areas or difficult terrain is obvious; civil use will follow if the requirements of safety and economic operation can be met.

Economic operation is always of paramount importance in civil aviation. The margin of profit is at best a very small quantity between the two vast sums of income and expenditure and quite small variations of either can have big consequences. If operating costs can be reduced, traffic will increase materially and the whole operation be put on a much more favourable basis. One foresees therefore the evolution of aircraft in the medium speed and short-to-medium range bracket where the emphasis is on capacity and efficiency rather than on out-and-out speed. Such aircraft would constitute efficient freight carriers—a business which will increase.

There is much speculation at the present time on the possibilities of civil aircraft travelling at supersonic speeds. We know already from our military experience that there is no particular reason why the progressive increase in the speed of civil transports should terminate at the speed of sound. The only questions are how much faster shall we go in the next step and when will it occur.

In trying to answer these questions, considerations arise additional to the technical problems. We can reasonably assume that civil aviation will continue to grow in volume—the indications are that it may easily double in the next 20 years—and there will always be room for a form of super travel over long distances at the highest possible speeds compatible with regular and safe operation. Such means of travel can demand a premium fare and are also a matter of national prestige. However, the productivity of supersonic aircraft in terms of load-carrying capacity per annum will be so great that a relatively small number of machines will meet likely requirements. It follows that the cost per aircraft will be very high and the cost of their development can only be considered a possibility with government assistance.

At the present time the major airlines of the World are making a big investment in subsonic jet aircraft which, in themselves, will be further improved and their utilisation widened. This big financial outlay must be absorbed and amortised before it can be repeated. For this reason and the many problems involved, I personally feel we shall be in the 1970s before we see

supersonic civil transports in regular airline operation. An interval of this order is not too long to design, build and thoroughly test an ambitious supersonic transport. In all probability a number of aircraft will first be employed for a period in military transport service before they are put into public service.

It seems improbable that we shall go to a lot of trouble just to fly at slightly supersonic speeds. Conversely I do not think that the first step will be so ambitious as to be a complete step into the unknown involving new methods of propulsion and fearful temperature problems. A few basic facts may be helpful.

(*i*) Range and productivity of operation increase with cruising speed.

(*ii*) Most aircraft today are built in alloys of aluminium and there is a vast background of experience with this material. Aluminium will not be used in structural members above a speed of, say, a Mach number of 2·3 because of the loss of properties due to kinetic heating.

(*iii*) Stagnation temperatures in the stratosphere are, approximately, 40°C for $M=1{\cdot}5$, 120°C for $M=2{\cdot}0$, 210°C for $M=2{\cdot}5$, 330°C for $M=3{\cdot}0$, and approximately 500°C for $M=3{\cdot}5$. The problems of construction, temperature control and operation rise in sympathy.

(*iv*) A plain turbo-jet can be used efficiently up to a speed of about $M=2{\cdot}5$. Beyond this speed complications in the form of afterburners or ram-jets are necessary to give greater jet velocity.

(*v*) High velocity jets intensify the noise problem, which is going to be difficult in any case.

With these observations I must leave the choice of speed to your good judgment and content myself with the power plants that make it possible!

Types of Engine Required

From this preliminary review of present trends, it is evident that we must consider engines covering the speed range between a Mach number of zero and, at least, $M=3$. So, I would like now to deal briefly with different types of engine in an ascending scale of flight speeds, beginning with power plants for helicopters.

HELICOPTER ENGINES

The helicopter operates at modest forward speeds and, generally, for short durations. Power/weight ratio is of paramount importance in determining the ability of a helicopter to hover with a specified payload. In this respect a gas turbine offers a weight which is perhaps a quarter of the weight of the equivalent piston engine. Fuel consumption may not be quite as good as for the piston engine, but it is very acceptable for the durations concerned. Moreover, a gas turbine provides a smooth drive through the reduction gears to the rotor and, if fitted with a free turbine, avoids the need for a clutch in the transmission. These advantages lead to further weight savings in the complete installation.

Multiple engines are required in the larger sizes of helicopter and particularly for their use in civil transport. Again, gas turbines can be coupled conveniently and form compact power plants gearing into the main rotor system. Normally, individual engines will be connected through freewheel arrangements so that an engine may fail without endangering the transmission. The reduction in torque from a failed engine can be arranged automatically to increase the power of the remaining engine (or engines) for the period of the emergency. This overload capacity of the gas turbine is a most valuable asset.

I am sure that we shall see a rapid transition of helicopters to turbine drive and we shall see more efforts to reduce weight and cheapen the cost of the power units.

SMALL TURBO-PROP ENGINES

Helicopter turbines when fitted with additional gears and propeller shafts constitute turbo-prop engines. It was expected at one time that the small turbine engine would replace the excellent four, six and eight-cylinder piston engines of 100–400 h.p. class which are in widespread use for personal and communication aircraft. The small gas turbine is attractive in size and is fashionable, but it has failed, so far, to approach either the consumption or the first cost of the alternative piston engine. Considerable efforts are likely to be made to improve the small gas turbine in these two respects and, as they succeed, the use of the piston engine in aviation will approach vanishing point.

MEDIUM TURBO-PROP ENGINES

In the medium power bracket (1,000–2,000 h.p.) the size of the components is more reasonable and it is easier to achieve the level of efficiency that makes for good fuel consumption. Moreover, the total number of parts and the cost of the fuel system and accessories changes little with size in this range. As a result, it is possible to build an efficient engine at a reasonable cost per unit of power.

The Dart has been a splendid engine in service but it has grown progressively and is now outside the arbitrary range of powers I have selected. My company is modifying the Gnome helicopter engine to make it a turbo-prop and, in this form it will provide a compact, light, and efficient engine of 1,200 h.p. developing, in time, say, to 1,500 h.p. (Fig. 2).

LARGE TURBO-PROP ENGINES

The Proteus in the Britannia and the Allison engine in the Electra are excellent examples of powerful propeller-turbines on two sides of the Atlantic. It may be said that the account of all gas turbines in service—turbo-jet or turbo-prop—has exceeded our best expectations in terms of reliability and good service. The gas turbine has already surpassed the best records obtained from reciprocating engines.

Outputs of 5,000 h.p. are already available and there are no particular reasons why powers should not rise considerably higher if required. So far, the rising power

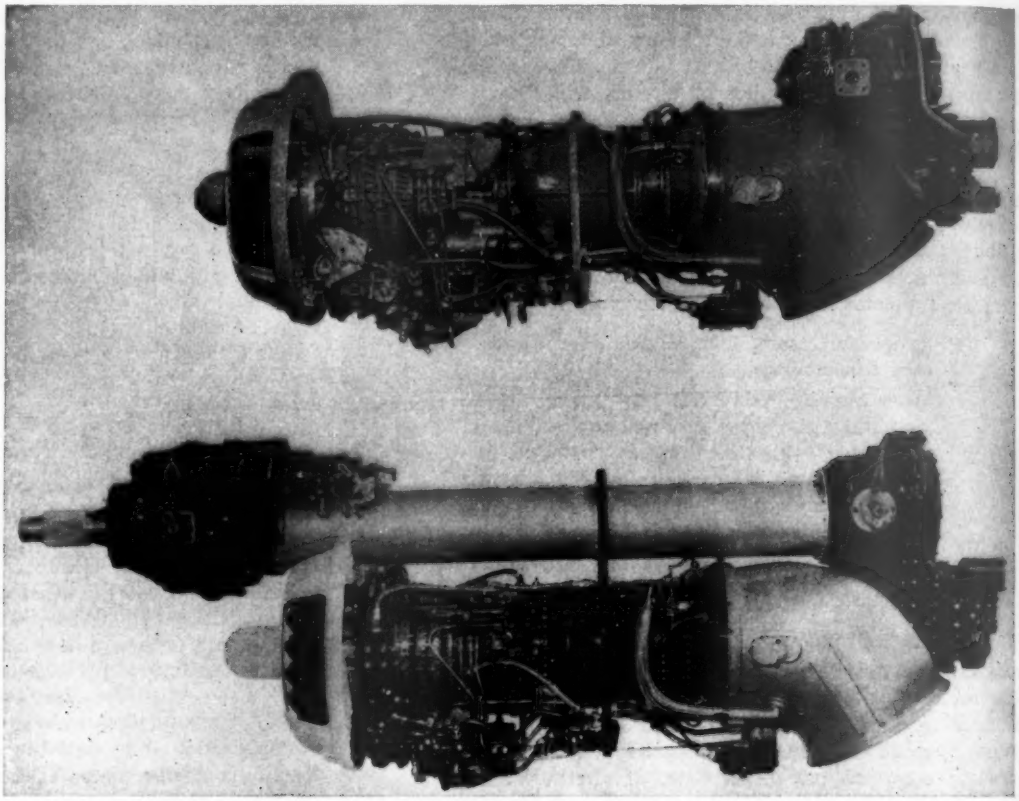

FIGURE 2. The de Havilland Gnome. Helicopter version (*above*) and (*below*) propeller version.

of the propeller-turbine seems to have been used mainly to increase the speed of flight. In consequence, its future is rather in doubt—through no fault of its own. After all, the strong point of the propeller-turbine is the excellent take-off thrust coupled with good overall efficiency and a flexibility of operation at moderate cruising speeds. It is wrong, in my view, to use the potential increases in power in pursuit of the jet. More appropriately the greater powers should be used for the large transports and freighters of the future to give excellent take-off and low operating cost.

TURBO-FAN ENGINES

Above a flight speed of, say, a Mach number of 0·65, it is difficult to design an efficient propeller installation: yet this flight speed is not high enough for efficient propulsion by pure jet. Temporarily, the situation has been met in jet aircraft such as the Caravelle and the Comet by cruising at fairly low turbine temperatures which give only a modest jet velocity. This, in effect, is trading away some of the internal thermodynamic efficiency of the engine to improve the propulsive efficiency of the jet. Further gains are possible if the jet velocity can be reduced and its mass increased without re-introducing the problems of the high-speed propeller.

A ducted fan driven by the engine is a way of converting a greater proportion of the jet energy into useful thrust. In its application the ducted fan may be regarded as a bridge between the propeller and the pure jet in giving more take-off thrust and better economy when cruising. The measure of improvement relative to the simple jet will depend on circumstances and particularly on the by-pass ratio, *i.e.* the relationship of the secondary fan flow to the primary engine flow. Representative figures from fitting fans to a subsonic jet installation would be an increase of 40 per cent in take-off thrust and an improvement of about 10 per cent in cruising fuel consumption. These are very worthwhile gains, especially as they are accompanied by a reduction in noise. The intensity of noise varies as the eighth power of the efflux velocity and the introduction of a fan may be expected to reduce the level of jet noise by something like 10 decibels. In addition, the better take-off performance permits a higher rate of initial climb with further reductions in the intensity and spread of noise as observed from the ground.

There are various ways of augmenting the air flow of a jet engine by means of a fan. The fan may be driven mechanically from the main rotor or it may have its separate driving turbine: it may be located at the front or at the back of the engine. Fig. 3 shows, at the top, the Rolls-Royce Conway engine in which the capacity of the low-pressure compressor is greater than that of the high-pressure compressor and the surplus air constitutes an additional "cold" jet surrounding the combusted "hot" jet. The lower half of Fig. 3 shows the Pratt and Whitney solution in which only the first

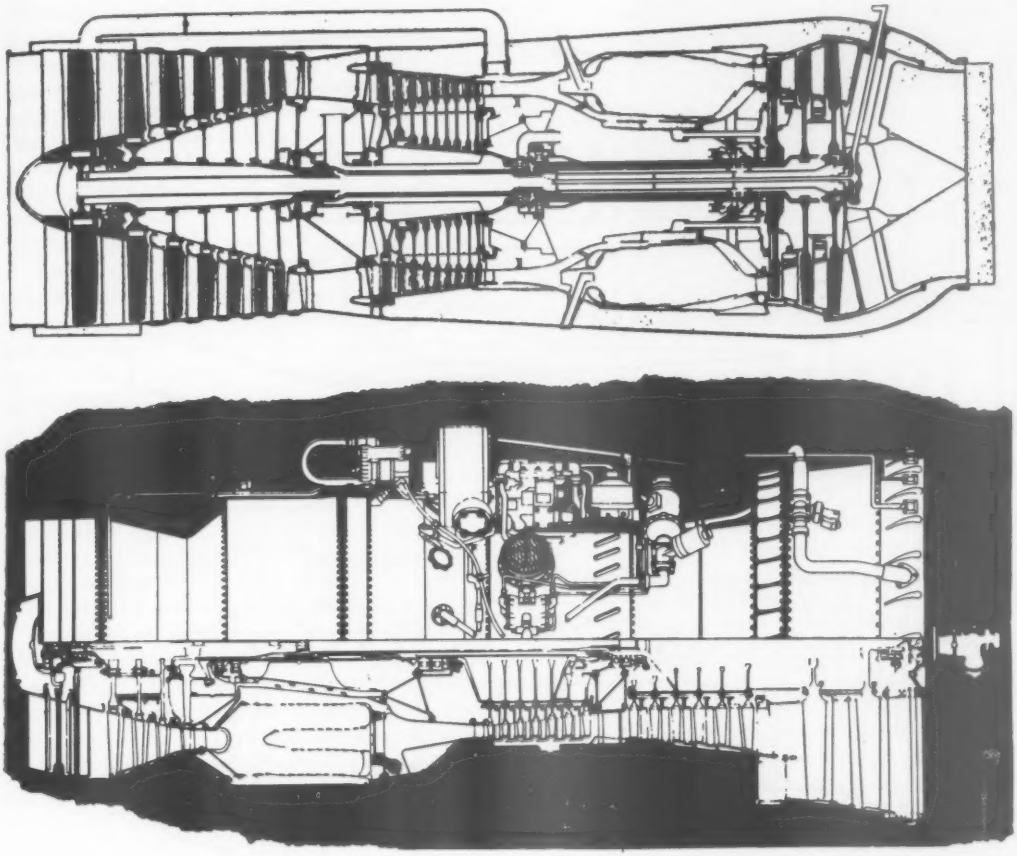

FIGURE 3. Turbo-fan engine with mechanical drive. (*Above*): Rolls-Royce Conway (*below*): Pratt and Whitney.

two stages of the low-pressure compressor are enlarged to produce the secondary flow. As in the case of the Conway, the fan drive from the main rotor is by mechanical means.

Figure 4 shows two arrangements of fan with independent turbine drives. The upper diagram shows the Bristol-Siddeley proposal in which a separate free turbine drives the fan stage in front of the main compressor. The lower half of the diagram shows the General Electric "Aft Fan" where again an independent turbine drives the fan, this time mounted directly on the blades of the turbine. A close-up of the combined turbine/fan rotor is shown in Fig. 5. Provided by-pass ratios and pressure ratios are similar, there is thermodynamically nothing to choose between these different arrangements. Personally I have a preference for the independent fan drive because it leaves the basic engine unchanged and gives greater freedom of choice of the fan speed and its proportions. Incidentally, the first "aft fan" for a jet engine was built by Metropolitan Vickers in 1943.

The installation of a ducted-fan engine needs much consideration. Mixing the hot and cold exhaust streams is advantageous from the performance aspect but this requires length and careful design if the internal losses are not to counterbalance the potential gains. Similarly, the flow to and from the fan must be uniform and unobstructed for optimum performance and freedom from blade vibration. Fig. 6 shows the nacelle used for the aft-fan installation of the General Electric CJ. 805-21 engine in a pod for the Convair 600 aircraft. Thrust reversal can be obtained by deflecting forward the combined exhaust streams when landing.

ENGINES FOR VERTICAL LIFT

As I have mentioned already, there is much interest at the present time in aircraft with the characteristics of vertical or very short take-off and landing. The power plant has an important part to play in the developments which will give aircraft the capabilities of the helicopter. Expressed another way, the helicopter engine is already a vertical lift engine and it is true to say that all vertical lift devices have some of the characteristics of the helicopter.

The first essential is that vertical thrust shall exceed the all-up weight; an obvious requirement but a necessary one at all times and in all climates! The next essential is that if an engine should fail nothing catastrophic will happen. This, in general, entails duplication of engines and means for the maintenance of stability and control. Vertical take-off needs a good margin of power: vertical descent, alas, can be achieved only too easily!

In an emergency the gas turbine has an important

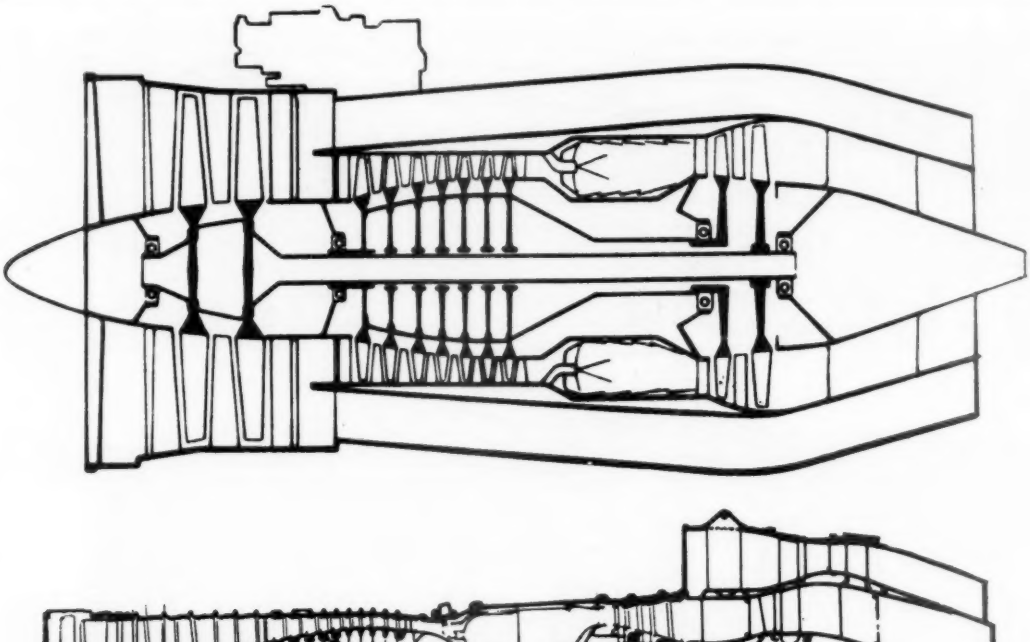

FIGURE 4. Turbo-fan engine with independent drive. (*Above*): Bristol Siddeley (*below*): General Electric.

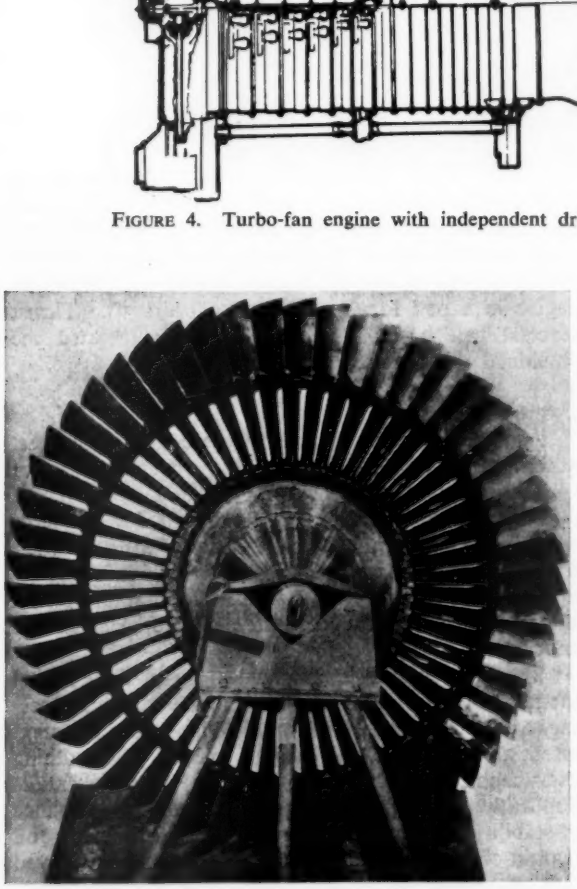

FIGURE 5. Aft fan for General Electric jet engine.

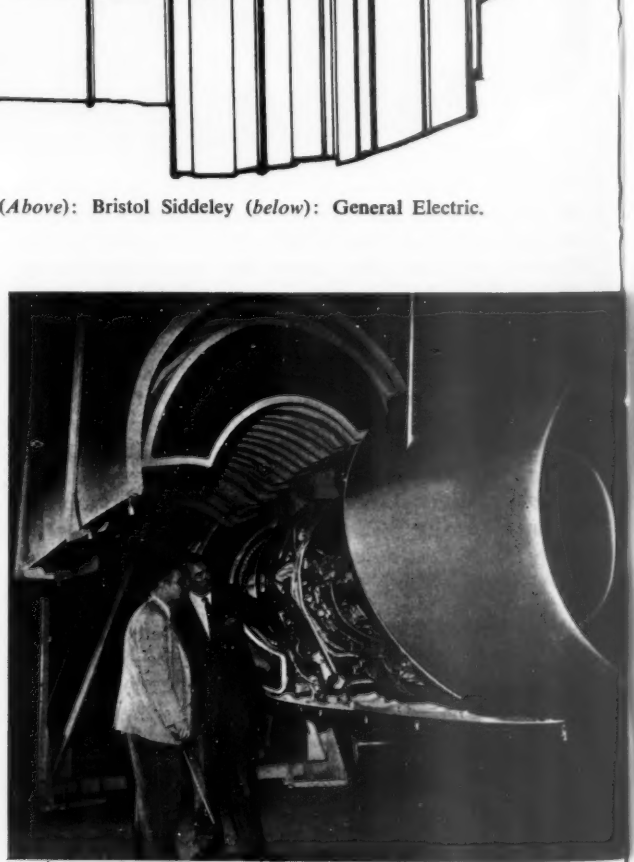

FIGURE 6. Turbo-fan in Convair 600 pod.

advantage in that it can produce a considerable excess of power with certainty and at short notice. Depending on the duration of the emergency, this may involve subsequent inspections or replacements, but this is a small penalty for the extra margin of safety provided. Control problems are always to the forefront. Normal aircraft control surfaces are of little value in hovering flight and immediate thrust control at strategic points is necessary for stability. Special problems arise during the transition from vertical to horizontal flight.

All sorts of ways have been proposed for achieving vertical take-off and in all cases the gas turbine is the most attractive power plant because of its light weight and adaptability. In the time available I cannot do better than illustrate a number of the possible arrangements.

The tilt-wing aircraft describes itself by its title and Fig. 7 shows the Kaman K.16. A tilt-wing aircraft uses large propellers rotating in opposite directions and interconnected by shafting against the possibility of power plant failure. Prompt pitch control gives the necessary stability in vertical flight. The propellers and interconnecting transmission must be regarded as part of the fundamental structure and must not fail.

A variant of the tilt-wing aircraft—suitable for short take-off and landing—is the multi-flapped configuration in which the wing is not tilted but distorted so that the slipstream is given a major vertical component. Such an aircraft is the Bréguet 941 shown in Fig. 8 and fitted with four Gnome engines as originally proposed. Each engine drives the interconnected propeller and shafting system through a free-wheel arrangement.

In England the Rolls-Royce Company has proposed the use of pure jet engines for vertical lift. They did pioneer work with the "flying bedstead" using two Nene centrifugal jet engines and bleeding air to four points for stabilisation. A proposal by Dr. A. A. Griffith for a high-speed transport is shown in Fig. 9. Multiple high-duty engines would be used for vertical lift: more economical jet engines for forward propulsion. With this arrangement idle engines are carried around during the cruising portion of the flight: on the other hand the lifting engines, having only a limited period of operation, can run very hot and be of very light construction.

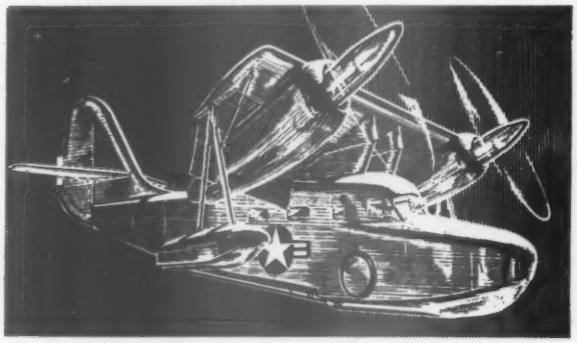

FIGURE 7. Kaman K.16 tilt-wing aircraft.

The propulsive efficiency in vertical lift is low and the consumption correspondingly heavy. Hence the duration of hover with this arrangement must be strictly limited.

As something intermediate between the large mass flow of a helicopter rotor and the small high-velocity flow of a lifting jet engine, consideration is being given to the use of lifting fans. Such fans augment the primary mass flow and give better fuel economy than a pure jet. A proposal of this type by General Electric is shown in Fig. 10. The exhaust of the jet engine can be diverted to drive a turbine mounted on the tips of the lifting fan which is situated in the wing. A possible aircraft configuration is indicated in Fig. 11. The fans give lift during vertical ascent and during the transition to horizontal flight. Thereafter the flow of gas to the fans is cut off, the fans stop and the engine efflux is used for propulsion in the normal way. The openings admitting air to the fans are closed during cruising flight by suitable louvres or covers.

A particular case of the lifting fan is the downwards deflection of the by-pass air from a turbo-fan engine to give lift. At other times the by-pass air is directed rearwards to give propulsion and good cruising economy. Fig. 12 illustrates a Bristol-Siddeley engine in which both the primary and secondary flows may be directed downwards or rearwards or at intermediate angles.

FIGURE 8. Breguet 941 S.T.O.L. aircraft.

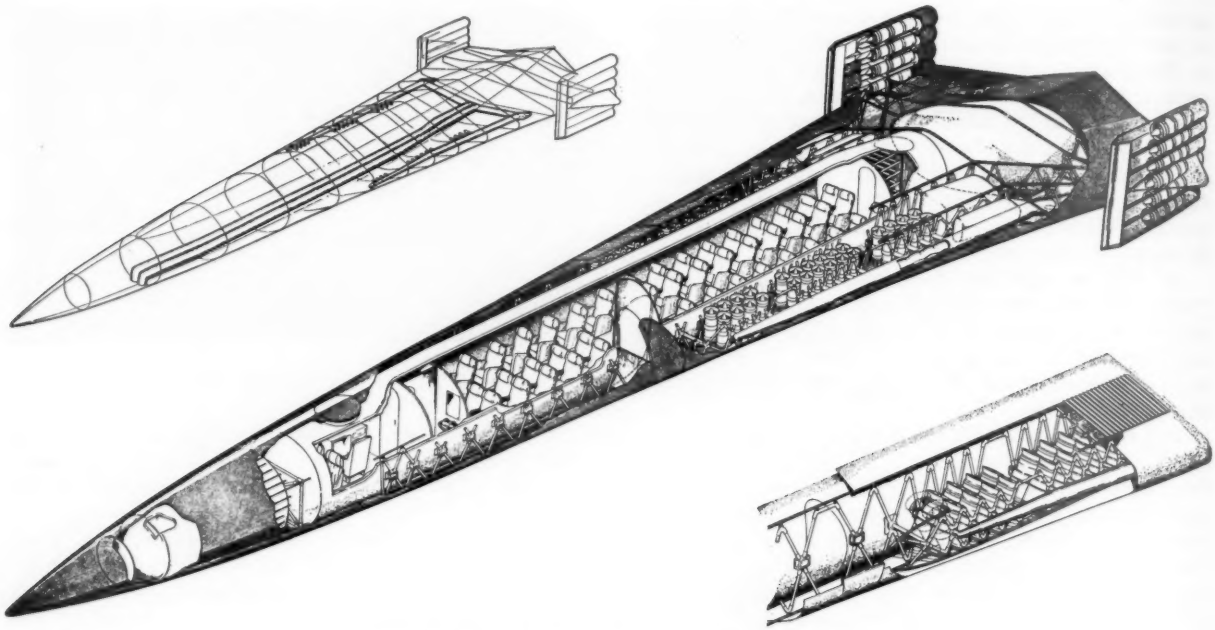

FIGURE 9. Proposed supersonic air liner with vertical lift.

The attractions of the various fan schemes are somewhat counterbalanced by the problems of installation and the need for control valves, duct work, and so on. The pros and cons of the various possibilities can only be properly assessed by the detailed study of an actual case.

Whatever system of vertical lift is used, it is essential that the centre of lift passes through the centre of gravity of the aircraft or thereabouts. This consideration governs the location of the lifting engines or fans or whatever combination of devices is used. For civil applications at least, questions of noise, ground disturbance, recirculation of hot air and dust, are matters of considerable moment. We have much to do before we can say we have successfully solved all the problems associated with vertical take-off.

I have spent some time on vertical lift because I

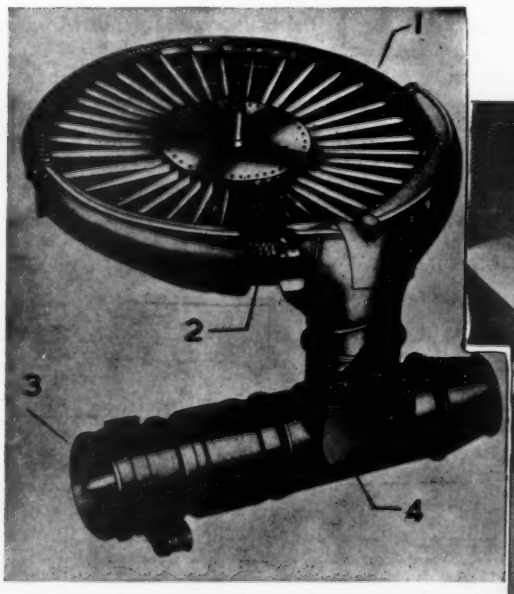

FIGURE 10. Jet engine with lifting fan.
(1) Lifting fan with tip turbine. (2) Turbine inlet volute.
(3) Turbo-jet engine. (4) Diverter valve.

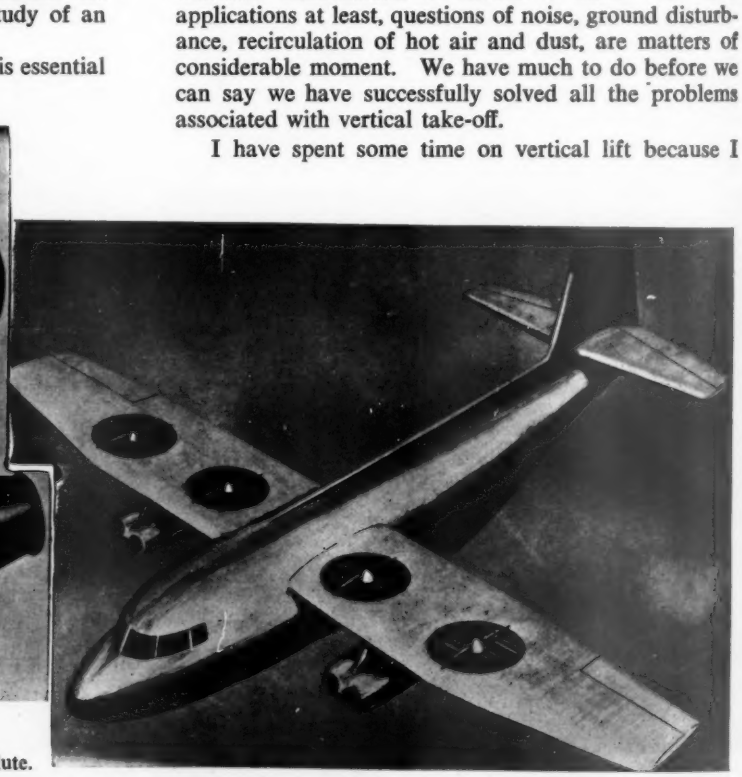

FIGURE 11. Suggested air liner with lifting fans.

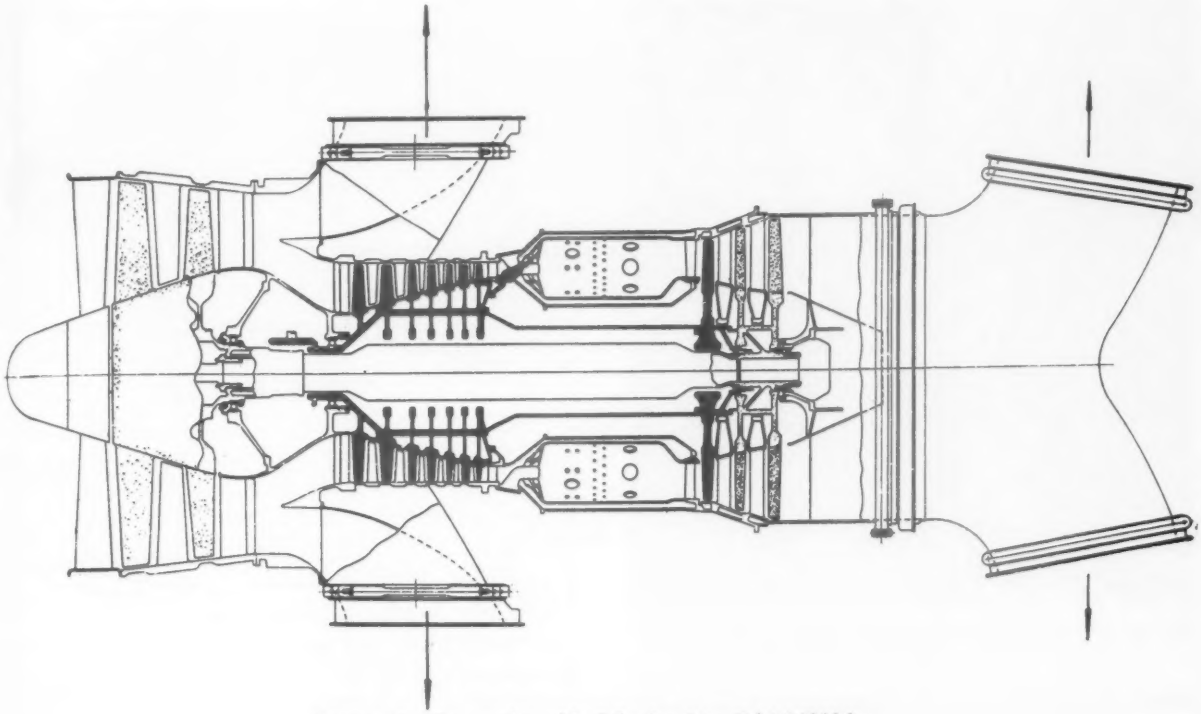

FIGURE 12. Fan engine with deflecting jets—Bristol-Siddeley.

think it is an important aspect of aviation in the future. Present investigations indicate that the facility of vertical take-off inevitably increases the direct operating cost of the aircraft. This is a factor to be watched, particularly in civil aviation. On the other hand, vertical take-off makes possible operations which are otherwise not feasible and can result in economies in other directions.

Engines for Supersonic Transport

I propose now to deal briefly with that other important aspect of our current developments, namely supersonic transport. In the earlier part of this paper we reviewed briefly some of the implications of supersonic flight; let us now consider the engine problems that go with it. Much has been said on this subject

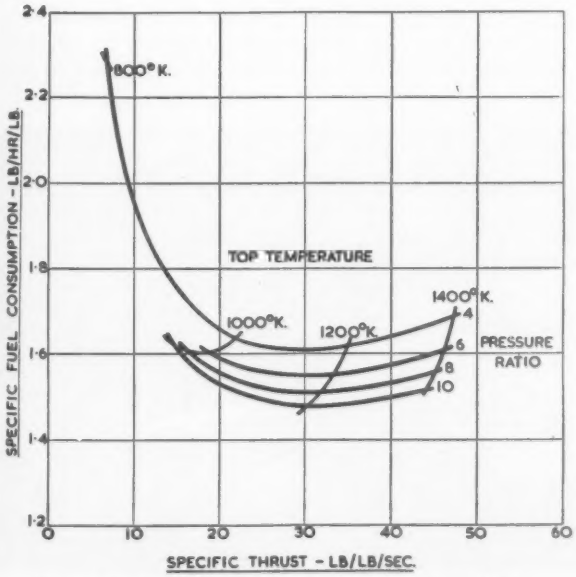

FIGURE 13. Design variables for a Mach number of 2·5.

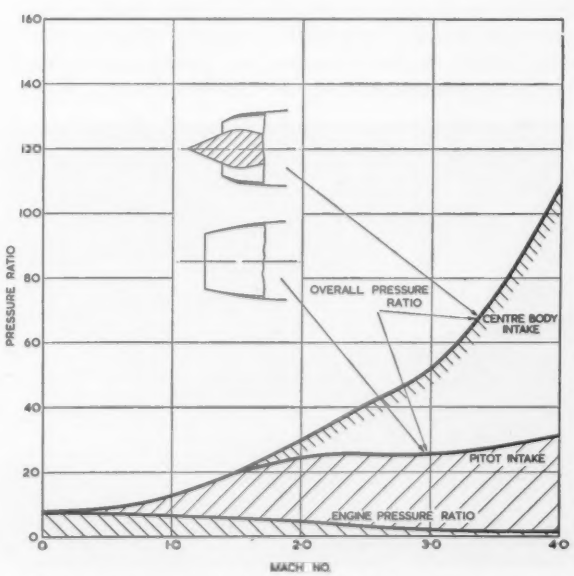

FIGURE 14. Intake efficiency and effective pressure ratio.

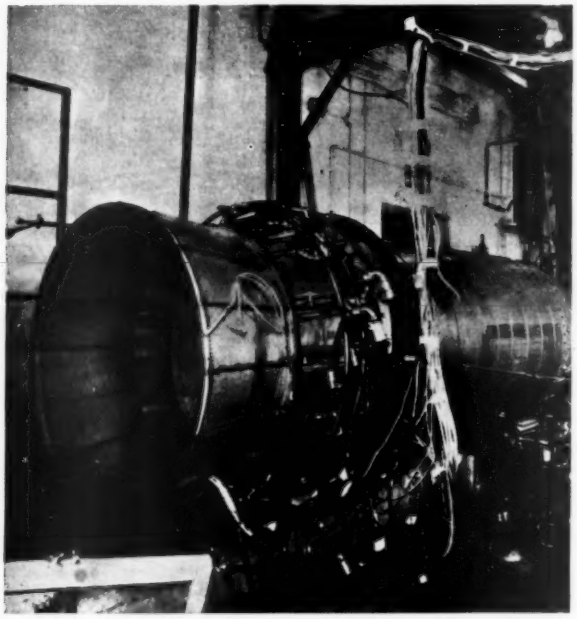

FIGURE 15. Variable convergent-divergent nozzle. Gyron Junior.

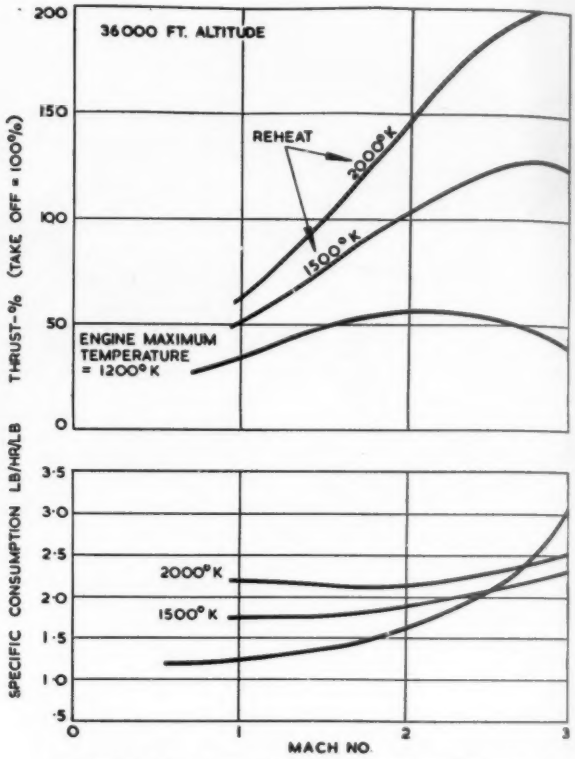

FIGURE 16. Effects of afterburning on performance.

already; indeed, I have myself been guilty, and it is not my intention to go over all the ground again.

The broad requirements for propulsion at supersonic speeds are now generally recognised and I will content myself with some of the salient features. What, for example, are the parameters of the design of a simple turbo-jet engine for a flight speed of, say, $M=2{\cdot}5$ in the stratosphere? Fig. 13 illustrates the effects of the different variables as affecting thrust and economy at present-day values for component efficiencies and working temperatures. To get maximum power from a given air flow we should work at a high turbine entry temperature and, unlike the subsonic jets of today, there is little penalty in consumption from so doing. Note also that for a chosen turbine temperature, an increase in the pressure ratio causes a reduction in power. A modest pressure ratio is all that is required both for this reason and the resulting simplicity and lightness of the assembly.

The relative unimportance of engine pressure ratio at these speeds is emphasised in Fig. 14: on the other hand, the diagram underlines the great importance of an efficient air intake system. At still higher flight speeds intake efficiency is increasingly important as affecting overall performance. This is another way of saying that

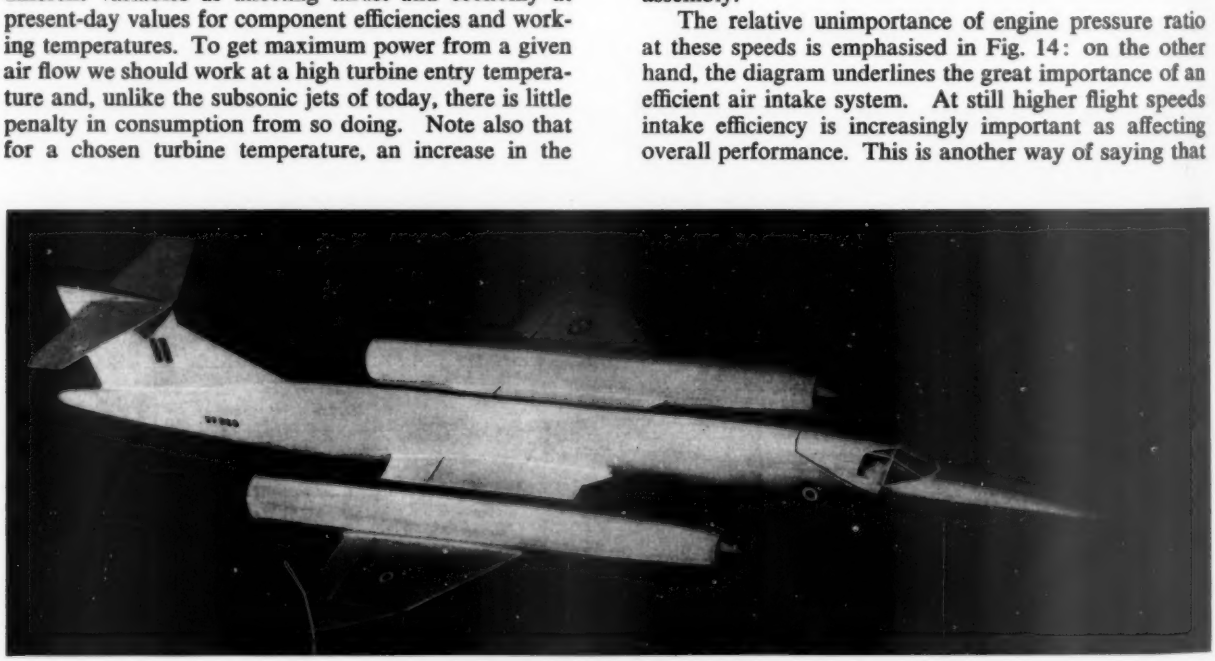

FIGURE 17. Bristol 188 supersonic aircraft.

FIGURE 18. Gyron Junior for Bristol 188.

the faster we fly, the more an air-breathing engine takes on the characteristics of the ram-jet.

The expansion ratio across the propelling nozzle rises with flight speed and a convergent-divergent form is required to develop the maximum jet velocity. A few years ago this seemed a formidable problem but designs have now been evolved which vary their area and change their form to cover the conditions of the complete flight régime. Fig. 15 illustrates a convergent-divergent nozzle fitted to the afterburner of the supersonic Gyron Junior engine. The throat diameter is automatically adjusted to maintain a constant turbine temperature over a range of jet temperatures between 1,000°K and over 2,000°K.

As flight speeds rise above a Mach number of 2·5 afterburning is necessary to maintain a sufficient margin of jet velocity without going to prohibitive temperatures in the turbine itself. The heat of compression becomes so high that little extra heat can be added before reaching the temperature limits of the turbine materials. However, a good deal of oxygen remains in the turbine exhaust and, under the prevailing conditions of high pressure, additional fuel can be burnt at quite good efficiency. Fig. 16 shows how the performance of a turbo-jet engine increases with different amounts of reheat at varying flight speeds. The increase in fuel consumption due to afterburning diminishes as the speed rises. In fact, at a Mach number of 3, a reheated turbo-jet can show an overall efficiency (measured as the work done against drag divided by the calories in the fuel burnt) as high as 40 per cent. Fig. 17 gives an impression of the Bristol 188 supersonic research aircraft. Fig. 18 shows the Gyron Junior power plant for this aircraft, complete with afterburner and variable nozzle as just described.

The conditions of operation of an engine at a Mach number of 3 are severe, with an air inlet temperature of 300°C and correspondingly high temperatures elsewhere. In effect, at these high speeds of flight there is no particular need for a compression process apart from the air intake: in fact, the compressor and turbine become rather an obstruction between the intake and the main combustion process in the afterburner. At $M=3$ no less than 75 per cent of the propulsive thrust is provided by the afterburner.

This brings us to the transition from turbo-jet to ram-jet. Unfortunately, the ram-jet is not self-driving at low air speeds and the aircraft must be accelerated by rocket or turbo-jet or by other means. Hence inevitably, we have a vehicle with mixed power plants using auxiliary means for take-off, climb and acceleration and

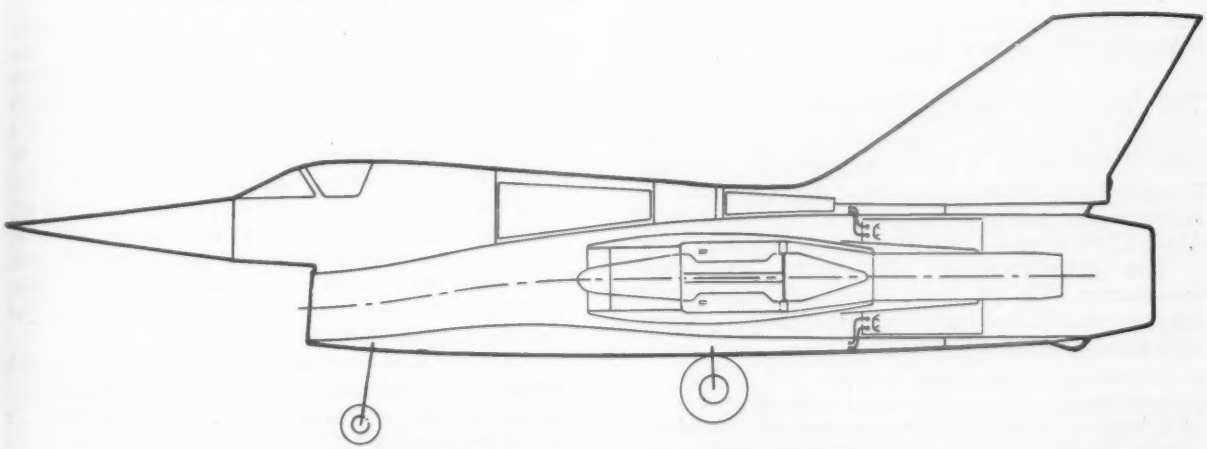

FIGURE 19. Turbo-ram-jet combination—Nord "Griffon."

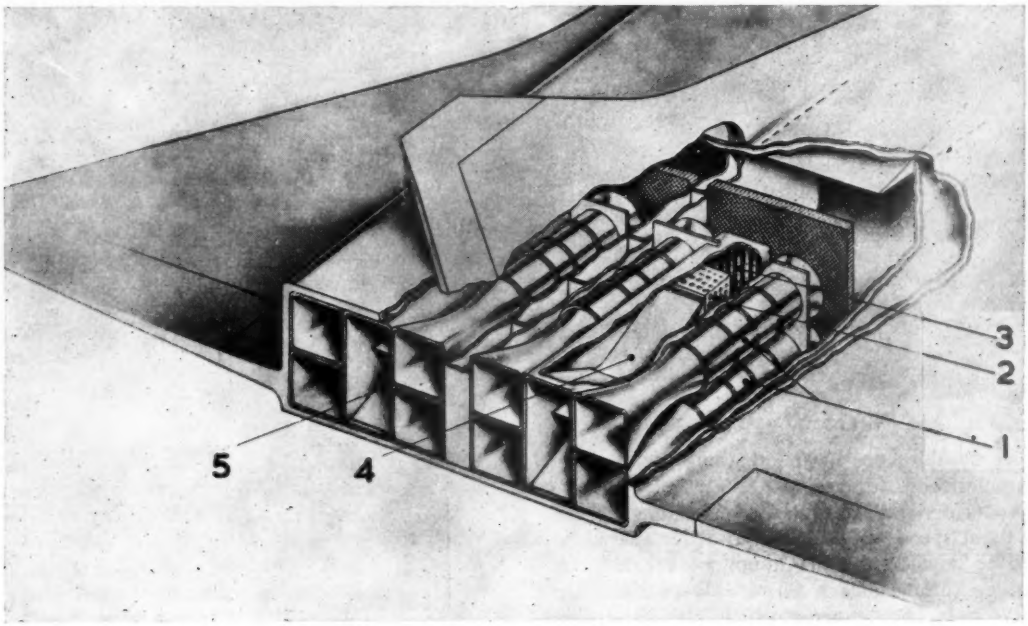

FIGURE 20. Proposed turbo-jet and ram-jet assembly—Bristol-Siddeley.
(1) Turbo-jet engines. (2) Ram-jet burner. (3) Fuel spray bars. (4) Ram-jet engine. (5) Variable exhaust nozzle.

using the ram-jet for the supersonic cruising portion of the mission.

The combination of a turbine and a ram-jet are typified in the Nord "Griffon" (Fig. 19) so ably described by General Daum in the 1959 Louis Blériot Lecture*. An important aspect of the combination is the complementary characteristics of the two types of power plant. This results in a light, powerful and economic assembly of a type which I feel will find application at speeds of $M=3$ and above.

In a recent paper, Dr. R. R. Jamison put forward a Bristol-Siddeley proposal for a supersonic transport aircraft combining turbo-jets and ram-jets. The power plant assembly is indicated in Fig. 20. It will be seen from the illustration that the turbo-jets and the ram-jets share a common supersonic intake but have independent combustion systems and exhaust nozzles.

The High Temperature Problem

From what has been said already, it is apparent that flight at high speeds is inevitably associated with high temperature operation. The carpet diagram of Fig. 13 indicates the performance gains to be obtained at $M=2{\cdot}5$ from operating at a high gas temperature.

The propeller-turbine also profits from high temperature. Fig. 21 shows the importance both of high compression and high temperature for giving power with economy when cruising.

*The Griffon Aircraft and the Future of the Turbo-Ram-Jet Combination in the Propulsion of Supersonic Aeroplanes. *Journal of the Royal Aeronautical Society*, Vol. 63, p. 327, June 1959.

It is obvious too—since high output is a function of temperature—that light-weight engines for vertical lift, helicopter operation, ducted-fan application, and so on, will use the highest temperatures they can employ with safety.

On all counts, therefore, the high-temperature turbine is of interest to engine designers and much work has been done in recent years to increase working temperatures. The main advance so far has been metallurgical and in about 20 years experience with the jet engine maximum temperatures have risen from 800°C (1,073°K) to perhaps 950°C (1,223°K). The process continues and new alloys—forged and cast—are becoming available which will permit further increases on today's temperature levels.

Another approach has been to cool the turbine blades so that maximum metal temperatures are considerably less than the local gas temperatures. de Havilland have used air blowing through both stator and rotor blading. In general, the stator blade is a fairly easy manufacturing problem because it can be formed from sheet or cast with internal passages. The rotor blades are much more difficult because of the high centrifugal stresses and because there can be no compromise in blade form at the cost of performance. Otherwise there starts a vicious spiral of rising temperature to offset the effects of inefficiency and yet maintain output.

We have been very successful in running at high temperatures using rotor blades forged or extruded with internal cooling passages. Fig. 22 is taken from an actual temperature plot of a cooled blade and shows how the gas temperature can then be increased. Note

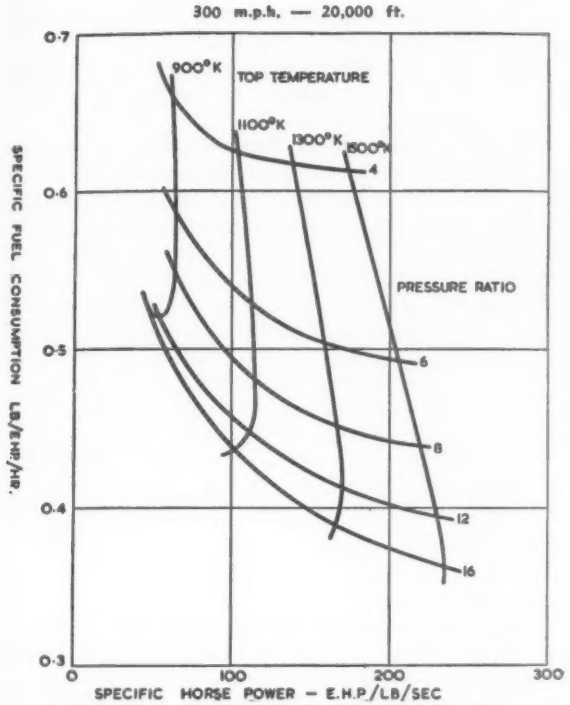

FIGURE 21. Design variables for a turbo-prop engine.

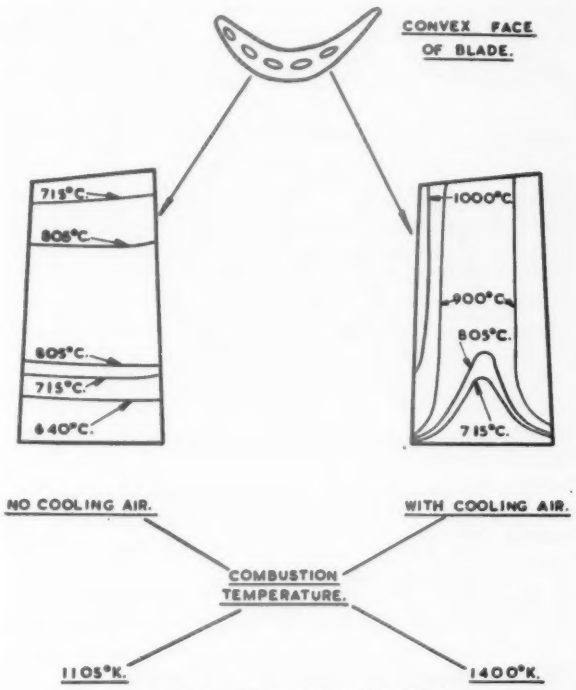

FIGURE 22. Air-cooled turbine blade.

that the combustion temperature is nearly 300°C hotter in the case of the cooled blade although the resulting metal temperatures are of the same order in the critical region at about one-third blade height. There is a cool "backbone" which gives strength to the blades and the hottest regions are now at the leading and trailing edges. Incidentally, and as a matter of interest, some of our earliest experiments were made using blades extruded and forged for us by a French firm.

The experience indicates that by using cooled blades gas temperatures can be safely increased by 150°–200°C. This is already as great an advance as has been made so far by metallurgical improvements. For the future we must combine good cooling with the best heat-resisting materials so that we have the double advantage.

The afterburner and the variable propelling nozzle must operate with gas temperatures which are appreciably higher than the melting point of the metal that contains them. This is only made possible by a system of skin cooling that protects the metal. A cooling flow costs something in maximum performance because it represents a pumping loss and some gas which is unburnt. A nice balance must be struck between this loss and a guarantee of safe operation.

Smooth combustion is a great help under these difficult circumstances. Flame vibration causes intense heat transfer and metal vibration which can be most destructive in a very short space of time. Fortunately, a heat shield which protects the outer skin from extreme temperatures and introduces a cooling flow has been found to be most beneficial in reducing combustion vibration.

Lines of Development

I have touched on the high temperature problem because it confronts all of us, but it is far from being the only problem. Besides the turbine and combustion system, high temperature operation affects the design of the compressor—demanding titanium or steel in place of aluminium: it affects lubrication of critical surfaces and it poses problems of local boiling and breakdown in the metering of the fuel.

The operation of the gas turbine engine is now well understood but a continual process of refinement goes on. The efficiency of the components is constantly being improved and this results in better performance. Big gains are becoming increasingly difficult to achieve but, as I have indicated, there are many possible variations of application which demand attention and which we shall exploit in the future. We can safely assume that there will be an even closer co-ordination of the vehicle and its means of propulsion. In addition, great efforts will be made to lighten and cheapen the designs of the future but not, in aviation, at the expense of overall performance.

I will conclude with a diagram or map of what I feel are the appropriate zones of operation of different types of aircraft engine. Fig. 23 must be regarded as indicative only because, in fact, a good deal of overlapping is possible.

(*i*) At the low-speed end there will be great interest in turbines of light weight and low cost.

(*ii*) In the medium-speed area the economics of operation are very important and we shall see efficient engines of various sizes applied to freighter aircraft and cheap transport.

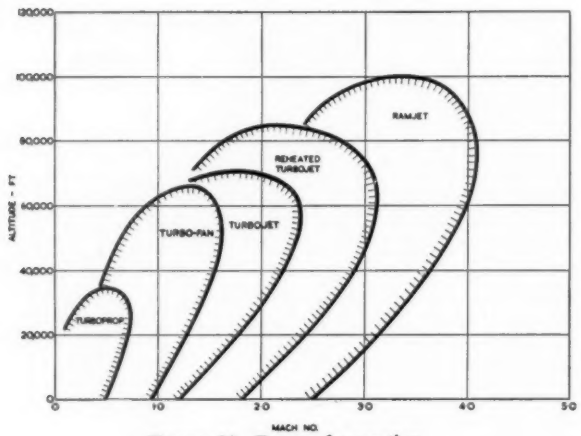

FIGURE 23. Zones of operation.

(*iii*) In the transonic speed range we shall see the plain jet being converted to the turbo-fan in the interests of better take-off, reduced consumption and less noise.

(*iv*) Above a Mach number of 2·0 the effects of ram compression become important and there will be an emphasis on intake design and the high-temperature operation of jet engines.

(*v*) Above a Mach number of about 2·5, afterburners will be used efficiently for the cruising portion of the flight and a variable geometry exhaust system is important.

(*vi*) Above a Mach number of 3·0 we enter the realm of the ram-jet, involving assistance for take-off and acceleration.

It will be seen from the foregoing that the complete spectrum of flight up to speeds of certainly $M=4$ can be covered by air-breathing engines in one form or another. As we fly faster we tend to fly higher in order to reduce aircraft drag. Finally, oxygen for combustion becomes a rarity at these great altitudes and we must take the working fluid with us as well as the heating agent. This brings us properly to the realm of rocket propulsion and to the vast possibilities of which the beginning is already well established.

Such is the march of time in the short 50 years since Louis Blériot made that first crossing from Calais to Dover on the 25th July 1909. It is worth recalling that on that memorable journey he flew at an altitude of 100 metres and a veloctiy of about one twentieth of the speed of sound.

ACKNOWLEDGMENTS

I am indebted to my colleagues for their assistance in the preparation of this lecture and to the willing co-operation of Bristol-Siddeley, General Electric, Rolls-Royce and others in supplying many of the illustrations.

The lecture was followed by a Reception and Cocktail Party and then by a Dinner at the Aero Club de France which was attended by a number of distinguished representatives of the French Government, the Armed Services, Research Establishments and the Industry and by Madame Blériot and Miss Jacqueline Cochran, President of the F.A.I.

Deck Landing*

by

Lt. Cdr. A. I. R. SHAW, M.B.E., A.R.Ae.S., R.N.

Introduction

Forty-two years ago—on 2nd August 1917—the first deck landing on a ship under way was made. A special platform had been constructed on the battle cruiser *Furious*, and it was on this prototype flight deck that Squadron Commander E. H. Dunning made the first successful aeroplane landing aboard ship. On touching down, his aircraft—a Sopwith Pup—was restrained manually by the (presumably) willing hands of a large number of officers and men. Two days later a second attempt ended in disaster. But from this beginning, like so many initial steps forward in aviation, a sad one, grew the Fleet Air Arm as we know it today.

The Aircraft Industry now produces aircraft which will achieve high performance in their operational roles and which, at the same time, possess the satisfactory low speed handling qualities so essential to safe and efficient operation from carriers. Yet, even with the great advances of the aeronautical sciences, it is still the pilot who must control the aircraft to a carrier landing and, in so doing, he is even now called upon to produce a greater effort of concentration and skill than is required in any other single flying operation. That he is able to do this is due, in part, to the Mirror Landing Sight, which is already a firmly established feature of Naval aviation.

Before entering upon a description of the mirror itself, it is appropriate to consider the need for some sort of visual control for the pilot of the approaching aircraft, and to examine the failings of the system most used in the past, namely the Batsman-Pilot combination. To be brief in discussing the requirements for a visual control system, let us accept that experience has shown such a system to be essential. This is obviously true at night, but even in the daytime and in good visibility there are two factors which make visual control vital. Firstly, there is the pitch of the ship due to rough seas, for whereas the pitch may be only too evident to an observer standing on the deck, it may look insignificant to the approaching pilot. Secondly, even on our longest carriers the landing space is only roughly 200 feet in length. Therefore the accuracy required in touch-down is of a very high order. Higher than is perhaps thought by the layman, who looks at a picture of one of our carriers.

Consider now, briefly, the failings of the visual control system which was in operation until the advent of the mirror. In this system the batsman, who stood on a platform just off the port quarter of the flight deck, held a pair of coloured "bats", rather like large table tennis racquets and, by a system of signals, he indicated to the pilot of the approaching aircraft any error which he detected in its flight path. The pilot was thus able to take corrective action and so ensure a safe arrival on the correct part of the flight deck at the correct speed. It is important to note here that the correct approach path for the aircraft was the path considered to be correct by the batsman. He relied entirely upon his knowledge and experience to determine the descent path which he instructed the pilot to follow. I need hardly add that the path the batsman thought correct did not always coincide with the views of the pilot and in this we see the human element introducing difficulties with the system. "The batsman is always right" was a rule most difficult to realise and it never quite overcame the pilot's powerful answer "Yes, but it's my neck, Jack".

A second disadvantage of this system arose at night when it was extremely difficult to illuminate the batsman satisfactorily so that his signals could be interpreted clearly. Many ingenious methods were used but none was able to dispel the aviator's belief in his old saying "Birds and fools fly by day, and birds don't fly by night". With the increase in approach speeds of post-war aircraft, night deck landings in such machines became extremely hazardous, and day landings only slightly less so. This leads us now to the final factor in the demise of the batsman system which, despite its drawbacks, had worked well for many years.

In the early days of the war the approach speed of our operational aircraft was in the region of 70 knots. By the end of the war our fighter aircraft were approaching at speeds of 85-90 knots and since then, with the advent of high performance jet aircraft, approach speeds have climbed steadily to the present day figure of 130-135 knots.

To appreciate what this means it is worth while considering what happens during the approach when the batsman-pilot system is in use. Firstly, assume that the aircraft diverges from its correct flight path. There is now a gap in time before the batsman appreciates this error, and a further gap in time while he decides what to do about it. He then acts on this decision by giving a new signal. The pilot now sees the signal and, while his brain digests it and passes the necessary corrective action, via hands and feet, to the controls of the aircraft, there is a further gap in time. All this, of course, is the human reaction time, and even the most quick witted would not deny that in this combination of batsman and pilot the human reaction time in total may amount to at least 2½ seconds. During this period of time, however, the aircraft has been continuing its approach and, at 130 knots, it has in fact travelled 180

*The majority of present-day Squadron pilots of the Fleet Air Arm have been brought up on the Mirror Landing Sight. This paper is a summary of a lecture given to the Glasgow Branch of the Society on 3rd November 1959.

yards through the air. If we assume that there is 30 knots of wind over the flight deck, then the relative speed of the aircraft's approach to the carrier will of course, be only 100 knots, but the aircraft will still be 140 yards nearer to the ship than it was when it first diverged from its correct flight path.

When one considers that it will take several seconds more for the pilot to resume flight on the desired path it becomes clear why the Navy needed a new system for controlling deck landing. Any such system must eliminate, so far as possible, human reaction time delays and, in addition, give the pilot a more immediate and positive indication of an error in his flight path. Furthermore, the new method must offer a greatly improved clarity, and an increased visibility range, at night.

The Mirror Landing Sight, invented by Cdr. H. C. N. Goodhart, R.N., and since developed by both the Royal Navy and the United States Navy has proved eminently successful in its task of achieving greater efficiency, and greater safety, in carrier operations.

The Mirror Landing Sight

Seen from the front (Fig. 1(*a*)) the mirror is rectangular.

It is four feet wide and three feet high, but these exact dimensions are not greatly important and they have, in fact, been altered since the mirror first came into Service use. A row of green "Datum lights" extends from each side of the mirror to indicate its horizontal centre line.

If we look at the mirror from above (Fig. 1(*b*)), we see that it is concave. Its curvature is that of an arc of a circle of 10 ft. radius. A side view (Fig. 1(*c*)) shows that the mirror is flat, and that from a distance of approximately 160 ft. a source light is beamed into it. This light is shielded from view from the opposite side. It should be obvious, from much familiarity with the shaving mirror, that an observer positioned somewhere above and behind the source light will, if he looks into the mirror, see the reflection of the source light in it.

A study of Fig. 2 will show that there is a direct relationship between the observer's position in space and the position of the reflection, or *image*, on the mirror. In fact, because the angle at which the source light beam strikes the mirror surface equals the angle at which it is reflected from the surface (angle of incidence = angle of reflection), we know that if the observer sees the image in the middle of the mirror, *i.e.* in line with the datum lights, then his eye must be on the line *AX*. If the image is seen at the bottom of the mirror then his eye must be on the line *BY*, and if at the top, his eye must be somewhere along *CZ*. The mirror is adjustable in tilt so that the angle of incidence, and therefore the angle of reflection, may be altered. Thus, by tilting the mirror, it is possible to set up a mean glide slope *AX* at any desired angle relative to the natural horizon and, by stabilising the mirror, it is possible to maintain this angle regardless of a ship's motion.

With a further look at Fig. 2 it will be seen that the lines *AX*, *BY* and *CZ* are not parallel. They are in

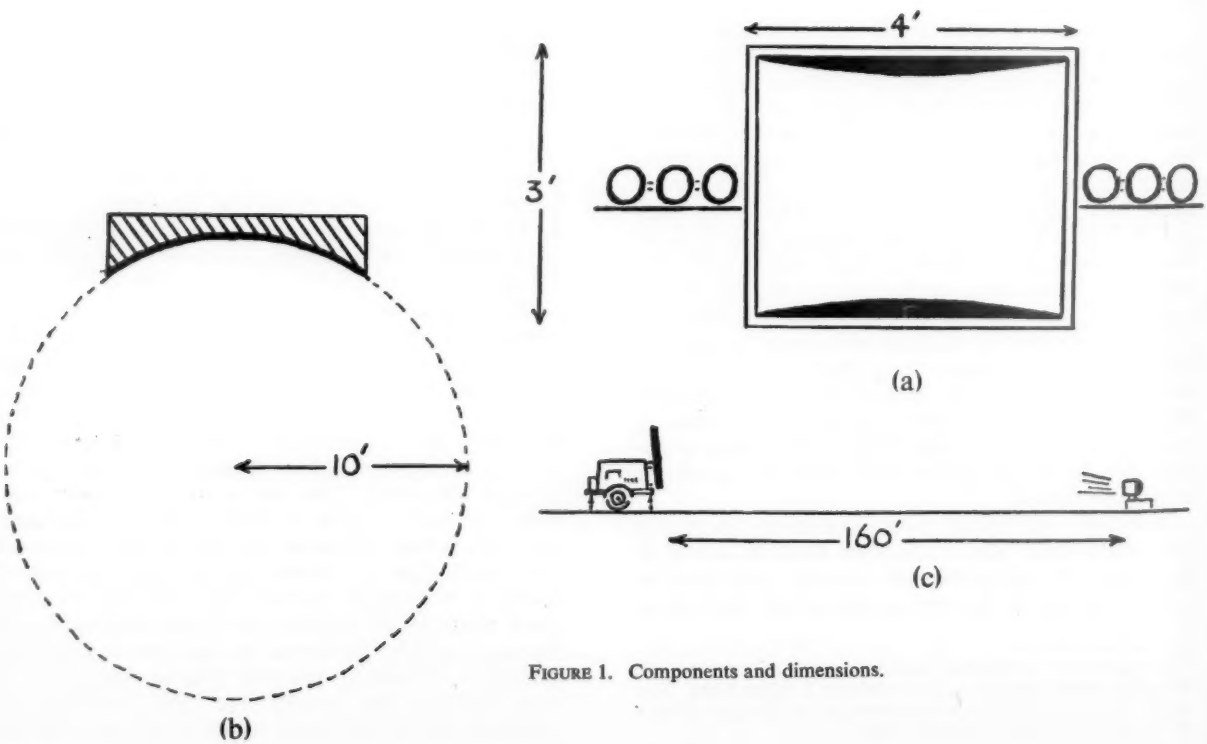

FIGURE 1. Components and dimensions.

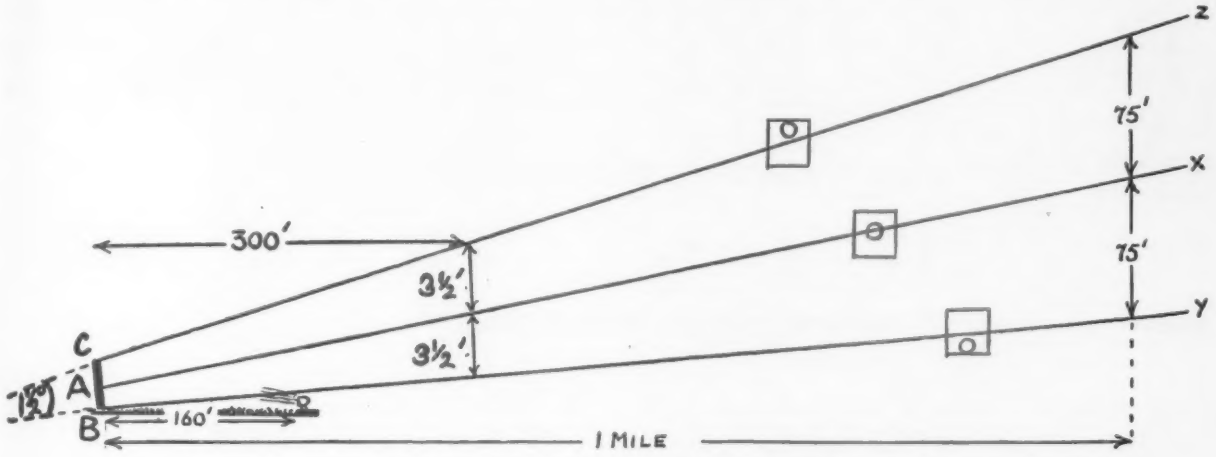

FIGURE 2. Diagrammatic sketch, not drawn to scale.

fact divergent from the mirror at an angle of about 1½°. This angle is dependent upon the vertical size and height of the mirror and the horizontal distance of the source lights from the mirror.

This divergence is extremely useful to the approaching pilot, for it means that, at a range from the mirror of one mile, he can be as much as 75 ft. above, or 75 ft. below, the optimum glide slope height and still see the image somewhere on the mirror. However, by the time the pilot has reached a point, say, 100 yards from the mirror, if he is as little as 3½ ft. too high or 3½ ft. too low, the image will be at full top or bottom of the mirror, and will disappear altogether if his error is further increased. The angular divergence therefore gives the pilot ample latitude, in the early stages of his approach, to pick up the image and then to settle down on the glide slope but, as his range decreases he is forced to become more and more accurate if he is to keep the image in view.

Looking down on the mirror and its source light from above (Fig. 3) it is seen that the curvature of the mirror gives a wide spread horizontally to the arc within which the image can be seen somewhere in the mirror. The same principle (angle of incidence = angle of reflection) applies here and it is clear that if the

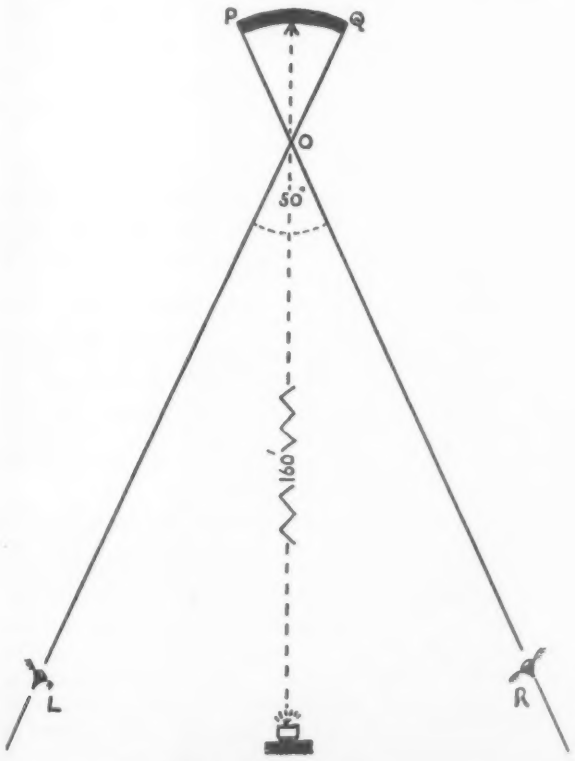

FIGURE 3. View from above.

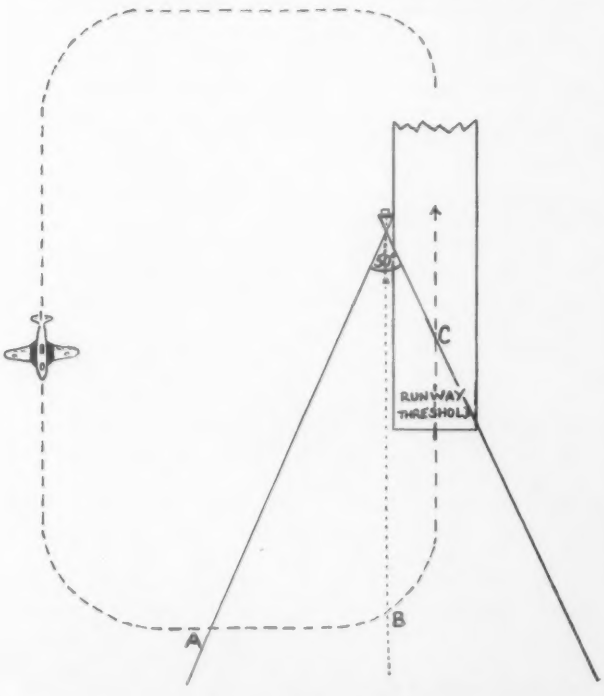

FIGURE 4. Mirror on runway.

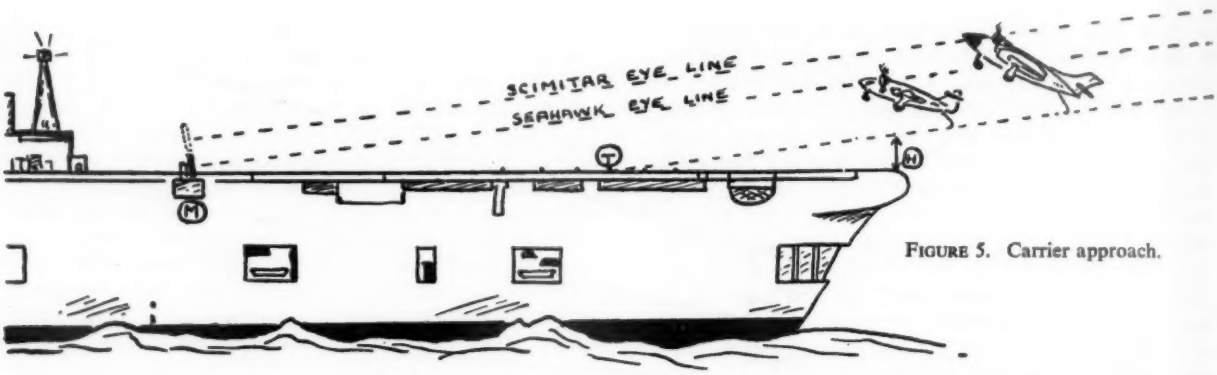

FIGURE 5. Carrier approach.

image is seen at the extreme right hand edge of the mirror then the observer's eye must be on line *LQ* and, if at the extreme left hand edge, on line *RP*. The angle *POQ* is approximately 50° and is determined by the width and curvature of the mirror and the distance of the source light from it.

Changing the scale somewhat, as in Fig. 4, it is seen that as an aircraft is making a circuit and approach to a mirror landing the pilot on reaching point *A*, will see the image appear at the extreme right hand edge of the mirror; provided, of course, that he is within the 1½° vertical spread mentioned earlier. He continues his approach and, as he arrives at point *B* the image is in the centre of the mirror. Thereafter, as he approaches in a straight path, with the centre line of the runway dead ahead, the image is moving steadily to the left until, on his arrival at point *C*, the image will disappear off the left hand edge. However, since it is the pilot's eye which is travelling down the glide slope, the wheels of his aircraft will touch down some distance before the mirror is reached and, by careful positioning of the mirror, we can ensure that point *C* is not reached before the aircraft has landed. What is illustrated by this view from above is that no useful information on "line-up" can be obtained from the mirror. The large horizontal spread enables the pilot to pick up the image early on his approach but, thereafter, he is given useful information on glide slope only.

Having outlined the system in principle we can now apply it to the aircraft carrier. Fig. 5 shows that the selection of a target wire (*T*) and a round down clearance (*H*) establishes the glide slope down which the hook of the aircraft is to descend. Because the eye of the pilot will be descending along a line above, and parallel to, the hook line the mirror must be raised or lowered to a position whereby its centre is intercepted by this eye line, as well as tilted to give the required glide slope angle. Since the vertical distance between the "eye" line and the "hook" line will differ with differing types of aircraft, the mirror height may require frequent adjustment during carrier operations.

Under conditions of pitch, the round down clearance may have to be increased. This can be achieved by maintaining a constant glide slope angle and accepting a later wire, or by aiming for the same wire and approaching at a steeper angle, or by doing both if the pitch is severe. A late target wire increases the chances of "bolting", while a steeper approach introduces greater handling difficulties for the pilot.

Summary

(1) The mirror system provides an accurate glide slope in space which, because it is adjustable, can be set up to accommodate all types of Naval aircraft. Furthermore, and again because it is adjustable *and* stabilised, a safe round down clearance can be assured under all conditions of pitch where deck landings are practicable.

(2) The mirror system provides the *pilot* with three vital pieces of information.

Firstly, it shows the sense of any error in glide slope; in other words it shows him whether he is high or low in relation to an established descent path.

Secondly, it shows him the magnitude of his error—the amount by which the reflection is displaced from centre is an indication of how *much* he is high or low.

Thirdly, by the rate at which the reflection is moving in relation to the datum lights the pilot receives an indication of the rate at which he is departing from, or returning to, the correct glide path.

(3) At night the mirror system shows its greatest improvement over the old method of control for, however expert the batsman, he was of little use if the pilot could not see him clearly, or early enough to interpret his signals.

So effective is the aid when used at night that experience shows the target wire to be engaged more regularly in darkness than in daylight. This is because the pilot is strongly tempted by day to disregard the mirror at the last moment, when he can see the deck clearly before him. Being human, he invariably believes he can do better on his own. The results rarely show his belief to be well founded.

(4) Is the mirror, then, the complete answer to all deck landing problems? Unfortunately that claim cannot be made for the system. For example, in conditions of poor visibility the approaching pilot may pick up the reflection too late to make use of the information which it transmits to him. But this problem is not confined to carriers, but applies equally well to airfield landings, and it seems fairly sure that reliable landings will never be achieved in very low visibility until the control is taken away from the pilot and given over to one of those familiar friends, the electrical black box.

The Australian Sounding Rockets Long Tom and Aeolus

by

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1. Introduction

The advent of the Skylark firings and the more recent trials of ballistic missiles such as the Black Knight firings, have demanded a continuous development of both ground and airborne instrumentation at Woomera Range; this in turn has raised the need for sighter rockets and instrumentation test vehicles with altitude capabilities in the 200,000-500,000 ft. range.

The need is currently being met by the rocket vehicles Long Tom and Aeolus. These rockets are of interest because they represent the first designed and built at W.R.E. that can be classed as high altitude rockets; also, they make possible the provision of relatively cheap and readily available vehicles for upper atmosphere research.

Aeolus has already been used in conjunction with the University of Adelaide in connection with a programme for the study of high altitude winds, and Long Tom has carried equipment to measure the frequency of incidence of meteoritic dust at altitudes above 200,000 ft. This latter experiment was made in conjunction with the Australian National University.

The first part of this paper contains a general description of Long Tom and Aeolus, followed by a summary of their respective performances. The second part contains a discussion of some of the design aspects of Long Tom. These apply in the main also to Aeolus.

2. General Description

2.1. LONG TOM

Long Tom is a two-stage rocket powered by four solid fuel Mayfly motors; these motors were designed and developed at the Rocket Propulsion Establishment, Westcott, and are the only major items that are "bought out". The general layout and leading dimensions are shown in Fig. 1.

The first stage consists of three Mayfly motors mounted "in parallel". The motors are located at their heads by an aluminium alloy casting and by a cast aluminium alloy spider just forward of the fin root leading edges. Some degree of fairing is provided by 18 SWG aluminium alloy sheet, as shown in Fig. 1. The rear fairing allows maximum advantage to be gained from the favourable body-fin lift interaction. The cast magnesium alloy fins are bolted directly to mild steel flanges welded to the motor venturis.

The second stage consists of a single Mayfly motor. This motor is mated to the first stage by means of a small cone on the nose of the boost head casting which picks up in the throat of the second stage venturi, as shown in Fig. 2. Separation at the end of burning of the first stage motors is effected by the differential drag of the two stages; an acceleration differential of the order of $9g$ ensures clean separation. Provision for instrumentation is made in the cylindrical compartment forward of the motor. This compartment is 9·2 in. in diameter and 35 in. long. Space for instrumentation or ballast is also available in the cast aluminium alloy nose cone, of semi vertex angle 7·5°. The cylindrical compartment can be subdivided anywhere along its length by pressure-tight bulkheads to provide a forward compartment sealed at ground level pressure, and a rear compartment vented to atmosphere. Three equi-spaced dural plate fins are mounted directly over the motor venturi on mild steel platforms welded to the venturi. These fins have steel leading edges notched into the dural plate to alleviate aerodynamic heating and erosion and to raise the critical flutter speed.

The all-up weight of the first stage is 1,400 lb.; the weight of the second stage varies between 520 lb. and 700 lb. depending on the instrumentation carried, giving a range of total weight at launch between 1,920 lb. and 2,100 lb.

2.2. AEOLUS

Aeolus is essentially a Long Tom second-stage rocket boosted by seven 5 in. light alloy plastic star motors in the first stage. The boost motor cluster is held at the rear by a light metal fairing, which also serves as a base for the four rectangular fins, and at the front by an aluminium alloy nose casting which is faired down to the diameter of the second stage. Mating of the two stages is again achieved by means of a small cone on the front of the boost nose casting which picks up in the venturi of the second stage. The boost assembly is shown in Fig. 3 and is of 16 in. diameter and 67 in. long. The all-up weight of the first stage is 600 lb. The weight of the second stage varies between 520 lb. and 650 lb., giving a range of weight at launch between 1,120 lb. and 1,250 lb. Long Tom and Aeolus are shown together, for comparison, in Fig. 4.

3. Payload

Payload can be carried in the cylindrical instrument compartment and also in the nose cone. The type and extent of instrumentation carried depends on the nature

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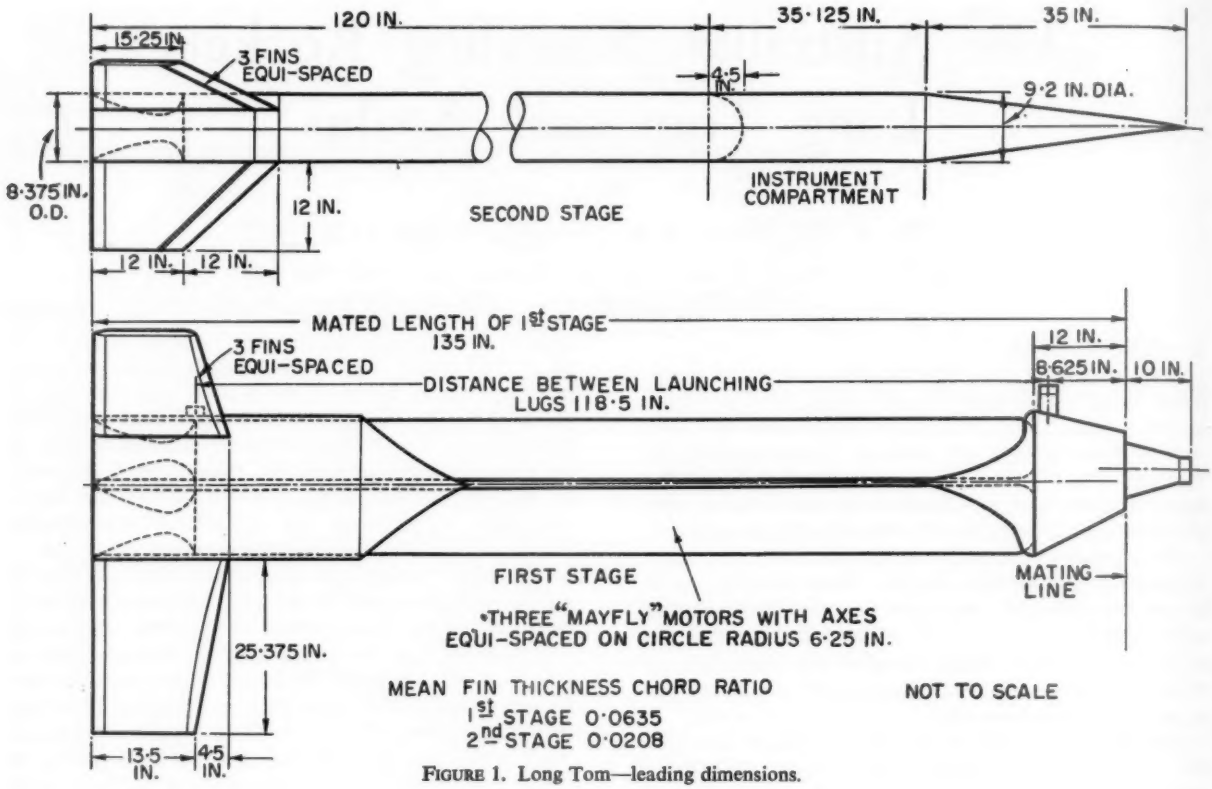
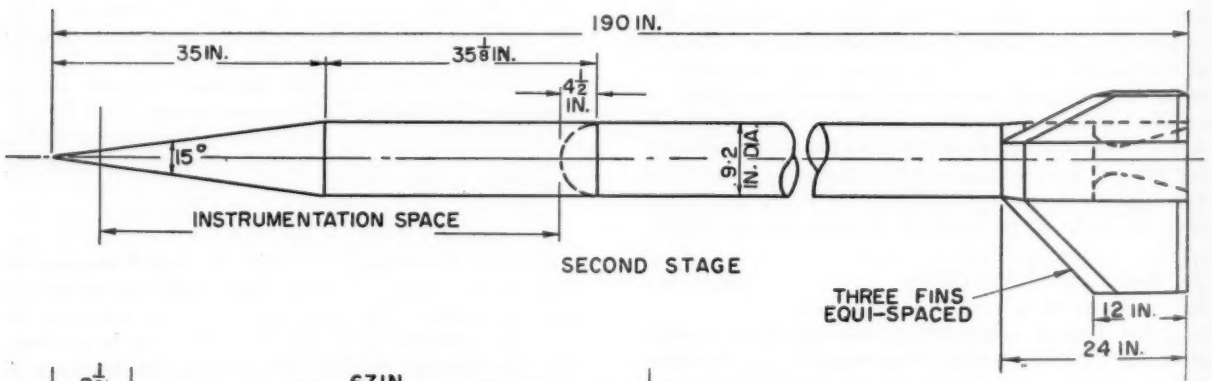


FIGURE 1. Long Tom—leading dimensions.



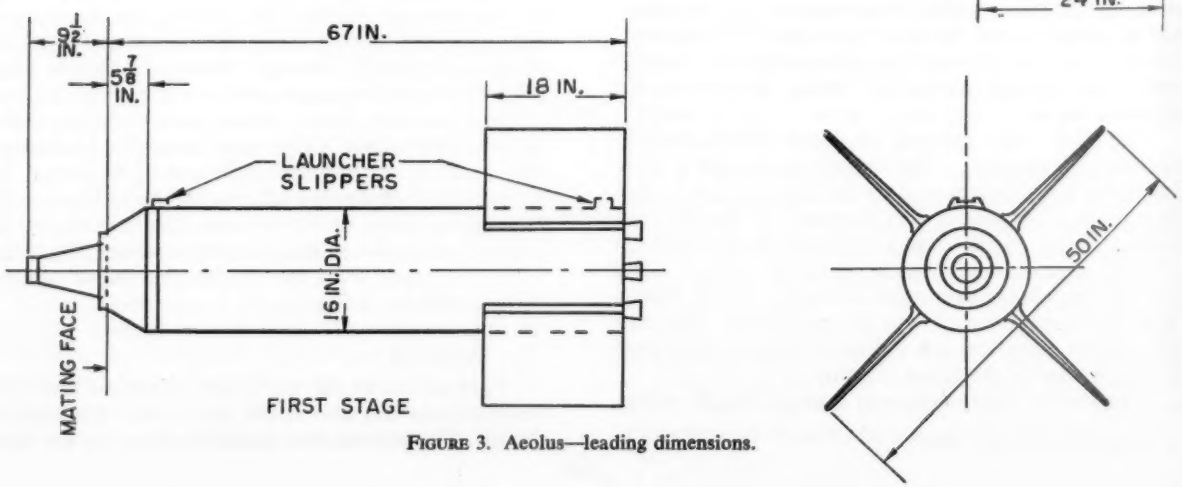


FIGURE 3. Aeolus—leading dimensions.

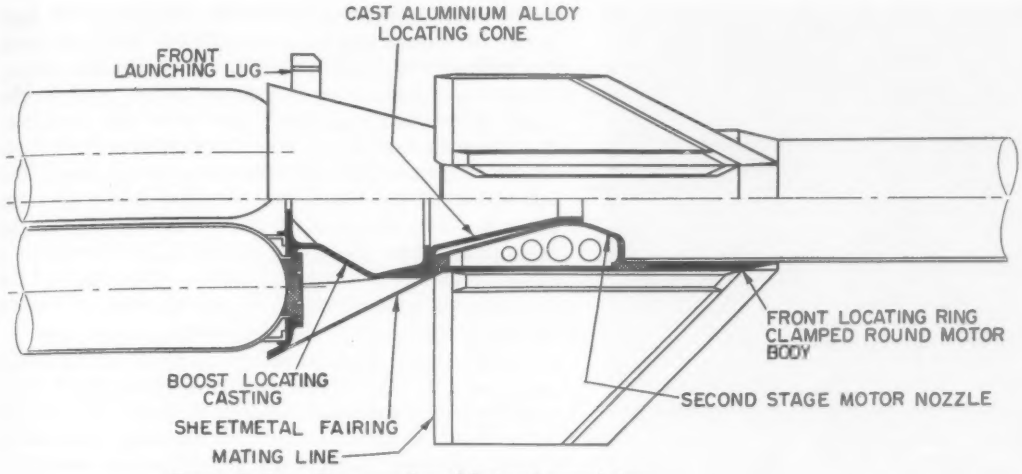


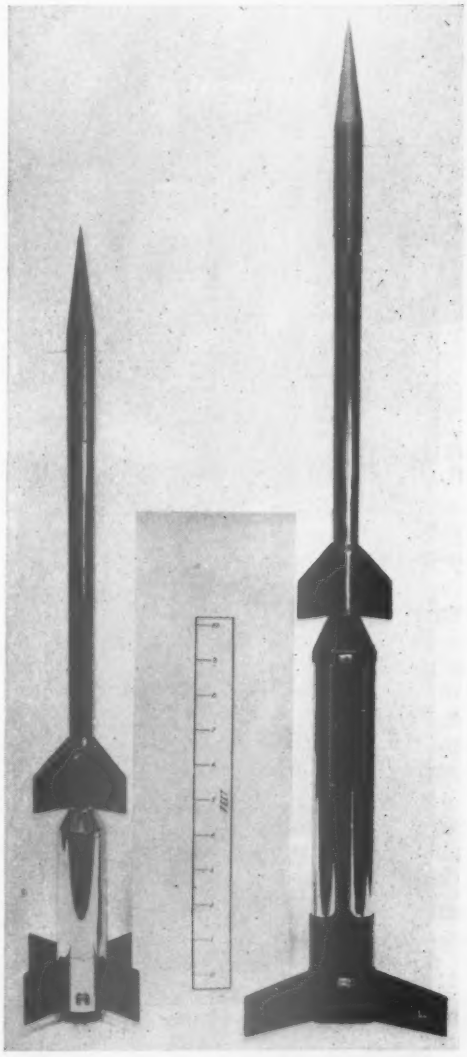
FIGURE 2. Long Tom—mating of first and second stage.

of the trial. The methods employed at Woomera Range to collect trials data have been described by Boswell[1] and will only receive brief mention here. When used in its prime role as a sighter rocket the minimum data required from Long Tom are time histories of its altitude, velocity and range, and for this purpose a W.R.E. multi-station radio tracking beacon (MTS unit) is carried as standard equipment. Also standard are the firing circuit clocks and batteries for ignition of the second stage motor. After inclusion of the MTS unit, firing clocks and batteries, some 1,950 cu. in. of space are still available in the instrument compartment and nose cone. In other cases data are required that can only be measured on, or in, the round itself, in which case a sub-miniature 24-channel time multiplexed FM/AM telemetry system[1] is used. Fig. 5 shows a typical installation in the nose cone of Long Tom. In this system the physical quantity to be measured is transformed into an e.m.f. or an inductance and fed into the modulator. In the modulator the quantity is transformed into a sub-carrier frequency which is used to amplitude-modulate the RF oscillator output. The system can handle 24 information channels by means of a mechanical switch which rotates at rates up to 120 revs./sec.

Individual channels can be sub-commutated if required. Sub-carrier frequencies are in the band 130-160 kc./sec., while the carrier frequency is in the band 435-490 Mc./sec.

From performance considerations the maximum allowable weight of the second stage, in the case of Long Tom, is 700 lb., allowing the carriage of 180 lb. of payload if this can fit the space available. Aeolus, with its less powerful boosting stage, is limited to a maximum payload of 130 lb.

Normally the instrument head of either vehicle does not separate from the motor after burning. Impact velocities are high, being of the order of 4,000 ft./sec. The rounds are completely destroyed by the force of impact. However, if recovery of any instrumentation is desired, the head can be explosively separated from the



Aeolus. Long Tom.

FIGURE 4.

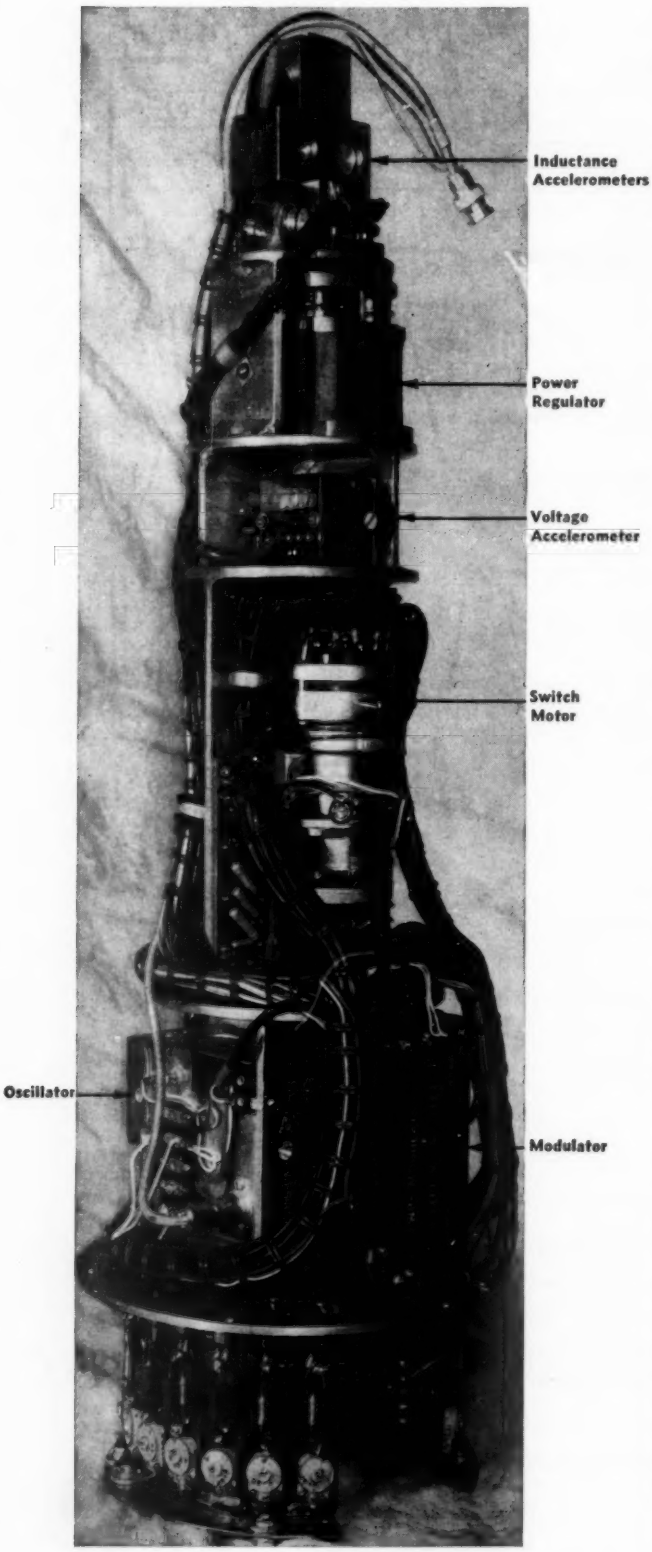


FIGURE 5. Installation of telemetry equipment in nose cone.

motor and brought to earth by parachute. A high degree of control can be exercised over the location of the explosive separation by the use of cordtex cutting charge. A special ring is inserted in the body at the point of required separation, just aft of the parachute compartment, and the cordtex charge is laid in a groove machined round the circumference of the ring. The outer skin of the round fits over the groove and the cordtex. The charge is detonated electrically at the appropriate time by a timing switch and produces a clean circumferential cut in the skin. The weight of the recovery system is about 12 lb., which must, of course, be subtracted from the useful payload.

With Aeolus, separation of the head occurs in the region of 150,000 ft. to 200,000 ft. when the round has a velocity in the region of 2,000 to 3,000 ft./sec. It has been found possible to deploy successfully a parachute at these altitudes and to obtain an adequate shock-free deceleration of the head without the use of a drogue; impact velocities are reduced to the order of 50 ft./sec. Fig. 6 shows the head of an Aeolus vehicle after recovery by a parachute released at 200,000 ft. In the one case where parachute recovery has been attempted with Long Tom, a nylon parachute released at 300,000 ft. failed to decelerate the head, which had an impact velocity of 400 ft./sec. (the terminal velocity of the head). On examination of the wreckage the parachute was found to be in a fused condition, indicating severe heating effects. The velocity of Long Tom at the time the parachute was deployed was approximately 3,000 ft./sec.

It is not possible to draw any firm conclusions on the limited evidence available, but it would seem that the successful deployment of a parachute at the altitudes in question must be sensitive to altitude, or velocity or both.

Probably the easiest way to ensure that the parachute is successfully deployed is to break up the round at high altitude and allow its unstable tumbling motion to persist to low altitude, say 20,000 ft., where the head has decelerated to its terminal velocity and the parachute may be safely deployed.

4. Launching

The same launcher, with slight modifications to the launching rails, can be used for both Long Tom and Aeolus. The launcher is of tubular steel construction and consists of a boxed beam pivoted near its mid point for training in elevation. The beam and its supporting structure are mounted on castors running in a circular track set in the concrete launching pad, thus allowing rotation of the launcher through 360° in azimuth. The Long Tom boost body is suspended by fore and aft lugs from two I-section rails of equal length mounted below the launcher beam. The lugs clear their separate rails simultaneously, thus minimising tip-off effects. The lugs on the Long Tom boost body are approximately 10 ft. apart, giving an effective launcher length of 10 ft. A launcher length of 10 ft. would result in Aeolus, with its less powerful boost stage, leaving the launcher with

rather low velocity, so the two rails are replaced by a single rail 23 ft. long.

Long Tom mounted on the launcher is shown in Fig. 7.

5. Performance

The trajectories followed by Long Tom and Aeolus are identical in sequence and may be divided into five separate phases:—

(*i*) The launching phase, starting with the ignition of the first-stage motors and ending when the combined stages clear the launching rail.

(*ii*) The first thrusting or boost phase, ending when the first-stage motors have finished burning and are jettisoned.

(*iii*) Coasting of the second stage before ignition of its motor.

(*iv*) The second thrusting phase, starting with the ignition of the second-stage motor.

(*v*) The final coasting phase of the second stage after motor burnout.

Only phases (*ii*) to (*v*), the flight phases, will be considered here.

FIGURE 6. Head of Aeolus after recovery by parachute from 200,000 ft.

FIGURE 7. Long Tom mounted on the launcher.

5.1. LONG TOM

At the end of phase (*ii*), first burning, Long Tom reaches a velocity of the order of 3,000 ft./sec. at an altitude of about 7,000 ft. The duration of this phase is between 4 and 5 seconds and is immediately followed by the separation of the two stages under differential drag action.

A number of factors govern the choice of time of ignition of the second-stage motor, and the optimum duration of phase (*iii*) for maximum peak altitude with an upper Mach number limit of 6 has been found to be between 15 and 20 seconds after launch. At the end of phase (*iii*) the round has decelerated to approximately 1,700 ft./sec. and has reached an altitude in the region of 40,000 ft.

During phase (*iv*), the burning period of the second-stage motor, the round accelerates to its peak velocity of approximately 500 ft./sec. at an altitude of 50,000 ft.

After the second-stage motor has finished burning the rocket coasts on until impact, passing though a peak altitude of between 300,000 ft. and 600,000 ft., depending on its weight and angle of launch.

The ground range covered depends on the weight of the second stage and the angle of launch, and is discussed more fully in Part 2. For typical firings the range is between 80 and 100 miles.

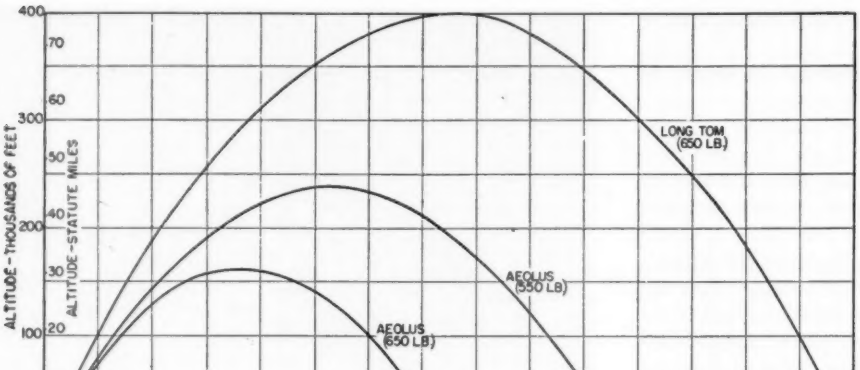

ALTITUDE - THOUSANDS OF FEET
ALTITUDE - STATUTE MILES
RANGE - THOUSANDS OF FEET
RANGE - STATUTE MILES
LONG TOM (650 LB.)
AEOLUS (550 LB.)
AEOLUS (650 LB.)

FIGURE 8. Typical trajectories for Long Tom and Aeolus, launched at 80° elevation.

5.2. AEOLUS

The boost motors fitted to Aeolus give about half the total impulse of the Long Tom boost stage, hence the performance is somewhat reduced. Aeolus reaches a velocity of 1,500 ft./sec. at 3,000 ft. at the end of phase (*ii*). The second-stage motor ignites 16 sec. after launch when the velocity is 850 ft./sec. and the altitude between 16,000 and 17,000 ft. The peak velocity at the end of second burning is of the order of 4,000 ft./sec. at 24,000 ft. Peak altitudes are in the range of 160,000 to 300,000 ft.

Typical trajectories for Long Tom and Aeolus are compared in Fig. 8. The Long Tom trajectory is for a second stage weight of 650 lb. and a launch elevation of 80°. This weight represents a useful payload of 130 lb. and the peak altitude achieved is of the order of 400,000 ft., with a range in the region of 70 miles. Aeolus, when launched at the same elevation, can carry 130 lb. payload to 165,000 ft., or 30 lb. payload (total second stage weight 550 lb.) to 240,000 ft., the ranges being 35 miles and 50 miles respectively.

PART II—THE DESIGN OF LONG TOM

NOTATION

C_D	drag coefficient
C_{D_B}	base drag coefficient
C_f	skin friction coefficient
D_B	base diameter
D_N	jet nozzle exit diameter
$\frac{dC_n}{d\alpha}$	slope of normal force curve
H_j	jet total pressure
M	Mach number
p_j	static pressure at jet exit
p_∞	static pressure of free stream
R	Reynolds number
$X_{c.p.}$	distance of resultant c.p. aft of tip of nose cone
$x_{c.p.}$	distance of c.p. (of component) aft of tip of nose cone
γ	ratio of specific heats for air

1. Choice of Propulsion Unit

The prime objective of the Long Tom design was to provide an unguided sighter rocket that was simple, could be readily prepared and would reliably achieve a performance in the 300,000 to 500,000 ft. altitude bracket with about 100 lb. payload.

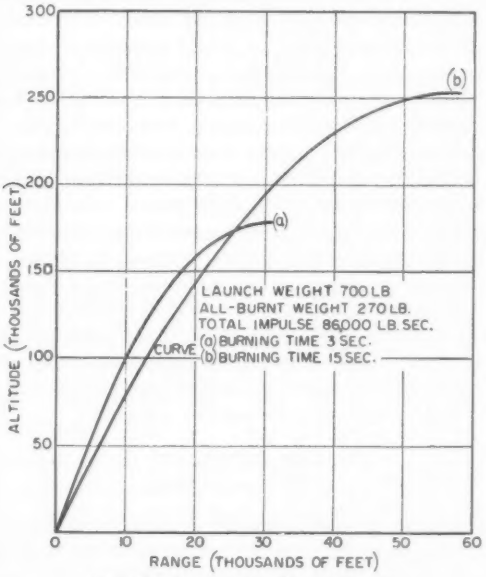
To be operationally acceptable the firing of this sighter should not be unduly restricted by adverse weather conditions. The simplicity should also extend to the launching and ground testing facilities. From the consideration of simplicity a solid fuel propulsion system was decided upon from the outset. The decision then to be made was whether to have a single-stage long-burning motor, or two stages of the same total impulse as the single stage, but each of shorter duration.

If high velocities are attained during the early stages of flight while the missile is still at low altitude, the drag penalty becomes high and power is wasted overcoming this. Fig. 9 compares two possible trajectories of a hypothetical single-stage vehicle having a total impulse of 86,000 lb./sec. A launch weight of 700 lb. and all-burnt weight of 270 lb. were assumed and a representative drag function was included in the trajectory computations. From Fig. 9(*a*), if the motor is allowed to burn for 3 sec. with an average thrust of 30,000 lb., curve (*a*), the altitude reached is 180,000 ft. When the motor burning time is extended to 15 sec. with an average thrust of 6,000 lb., the peak altitude increases to 250,000 ft. (curve (*b*)). Fig. 9(*b*) shows the velocity-height relationship for these two cases. With the short-burning motor the rocket reaches a peak velocity of 5,250 ft./sec. at 8,000 ft., the drag at this point being 3,400 lb. and the maximum acceleration during burning being 76*g*. With the long-burning motor the rocket takes 32,000 ft. to reach a peak velocity of 4,500 ft./sec., when the drag is 1,300 lb. The peak acceleration during thrusting is 13·5*g*.

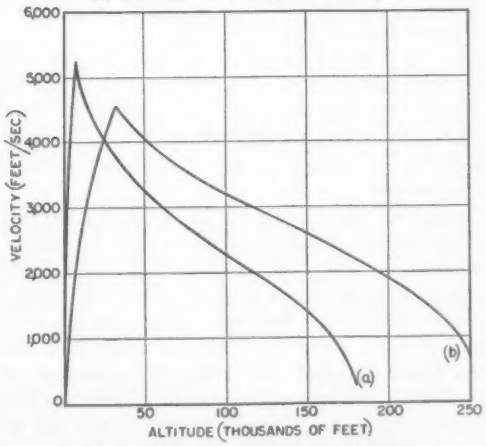
From these results it would appear desirable to keep the mean thrust level down so that the rocket has a relatively low acceleration, spread over a long burning time. However, this has its disadvantages for an unguided ballistic rocket. A rocket with axial thrust is particularly susceptible to deviation of the trajectory due to wind effects during its thrusting period, so that if

the velocity off the end of the launcher and subsequent accelerations are too low, the problem of estimating and correcting for winds varying both in speed and direction over a considerable height range becomes rather severe. One is then faced with the choice of laying down restrictions on permissible meteorological conditions for firing or, of making an extremely long and cumbersome launcher to ensure an adequate velocity when the rocket becomes airborne. Both these vitiate the objectives which the rocket was designed to attain.

The foregoing example assumes that in both cases the total impulse is employed in a single-stage continuous-burning motor, the carcase of which is retained throughout the flight. By using two stages, the drag penalty incurred by the single short-burning stage can, to some extent, be overcome while the advantages of high launch acceleration are retained. The first stage is jettisoned immediately it has finished burning, thus reducing the drag and the dead load to be carried.



(*a*) Altitude as a function of range.



(*b*) Velocity as a function of altitude.

FIGURE 9. Effect of burning time on performance.

In general, maximum peak altitude will be reached if the second-stage motor is ignited immediately; however, this would result in an excessively high peak velocity at a relatively low altitude, with consequent excessive dynamic pressures and skin temperatures. In fact, ignition of the second-stage motor can usually be delayed for a fairly long period before the peak altitude is significantly reduced, but the peak velocity is reduced and occurs at a higher altitude. Long Tom coasts for 20 seconds before the second-stage motor is ignited and 25,000 ft. are gained during this coasting period. The second-stage motor is then ignited and the rocket is allowed to coast on after burning without separation from the head. At the end of second burning the rocket has reached an altitude between 50,000 ft. and 60,000 ft. and has a velocity of the order of 5,000 ft./sec. At these altitudes the air density is low and the high velocities achieved by the short-burning high thrust motor do not impose such a high drag penalty as at the end of the first burning period. In fact, in the second burning stage the long-burning motor shows little gain over the short-burning one from the altitude performance point of view. This two-stage technique is about as efficient as having one long-burning non-separating motor when considered in terms of useful payload and, because the range of solid fuel motors available at the time favoured it, this was the technique adopted for Long Tom. These remarks apply only to rockets of performance capabilities similar to Long Tom and do not necessarily hold for the problem of optimum thrust programming in general.

It is interesting to compare Long Tom with the upper atmosphere research rocket Skylark[2] which has a single long-burning motor and is non-separating. The useful payload is of the same order—150 lb. for Skylark, 130 lb. for Long Tom. Skylark is fired from a launcher some 100 ft. in length; Long Tom employs a 10 ft. launcher, yet the wind dispersion problem with Long Tom is slightly less severe than with Skylark. The Skylark total impulse is roughly twice that of Long Tom and yet the peak altitudes achieved are comparable, about 500,000 ft. for Skylark, 400,000 ft. for Long Tom. Although the useful payloads are of the same order, Skylark actually lifts a total dead weight of 800 lb. to 500,000 ft., while Long Tom lifts only 400 lb. to 400,000 ft.

The significant factor is that Skylark was designed to lift its payload, which consists of a wide variety of research apparatus, into the upper atmosphere without subjecting it to very high acceleration. Skylark does not exceed an acceleration of 9*g* at any stage of its ascent, whereas with Aeolus and Long Tom the type of apparatus carried as payload must be able to withstand accelerations as high as 50*g*.

As has already been mentioned, an increase in the burning time of the second stage without change in the total impulse would not improve the altitude performance overmuch, since the drag penalty incurred by high velocities is much reduced at the altitudes where the peak velocity is reached (60,000 ft.). An increase in burning time of the boost stage with a reduction in the mean thrust, acceleration and peak velocity, would

certainly result in a significant gain in altitude; but, from the point of view of wind deviation reasonably high launch velocities (and therefore accelerations) are desirable if a short launcher length is desired. The answer lies in shaping the thrust characteristic to give a high acceleration during the launch phase and a reduced thrust over an extended burning time for the remainder of the thrusting phase. Modern techniques in solid fuel motor design render this type of thrust shaping a possibility, which will almost certainly be attempted in some future version of Long Tom.

2. Drag

Having decided on the propulsion unit, a preliminary layout of the two stages can be made and an approximate calculation of the weight and centre of gravity can be carried out for the various flight stages. Before stability estimates can be made a knowledge of the trajectory is required and to compute this, the drag coefficient C_D as a function of Mach number and altitude must be computed. All normal force and drag coefficients are referred to the body cross-sectional area of 0·462 ft.²

During the first thrusting phase, when the two stages are combined, supersonic velocities up to a Mach number of 3 are achieved at altitudes of some 6,000 ft. Drag forces are only a small proportion of the thrust and need only be known approximately. After separation of the stages, particularly in the first coasting phase, drag must be estimated as accurately as possible if any reliable trajectory computations are to be made.

Drag forces are normally divided into drag at zero incidence and induced drag, or drag due to lift. Since in the performance studies carried out at this stage the round is assumed to follow a ballistic trajectory, only zero incidence drag forces need be estimated. These are further divided into profile drag or wave drag, skin friction and base drag.

Wave drag arises from the shock pattern at the nose of the body, the shock patterns at the fin leading edges and from the shocks arising at any surface discontinuity, such as fin-body junctions or any discontinuous increase in body contour slope. Both Long Tom and Aeolus have a conical nose of 7·5° semi-vertex angle, fitted to a cylindrical afterbody. The wave drag of cones can be derived from the data computed by Kopal[3].

Both the first and second stage fins are of parallel-double wedge section and their contribution to the wave drag can be computed from the charts prepared by Bishop and Cane[4].

The effect of Reynolds number on body skin friction is given in the case of a turbulent boundary layer under zero heat transfer conditions by the semi-empirical formula[5] for the mean skin friction coefficient C_f:—

$$C_f = 0{\cdot}074R^{-1/5}\left(1+0{\cdot}9\frac{\gamma-1}{2}M^2\right)^{-2{\cdot}2/5}$$

where R = Reynolds number based on overall body length l.
γ = ratio of specific heats for air.
M = free stream Mach number.

The results given by this formula are similar to those given by other semi-empirical formulae.

Perhaps the most difficult drag effect to estimate with any accuracy is the base drag both with motor off and during thrusting. Many factors affect the pressure on the blunt base of a body—such as body shape, presence of fins, boundary layer thickness and Reynolds number, although for a fully turbulent boundary layer this is small. The presence of a jet can also substantially alter the base pressure. Some useful work has recently been done by Love[6] in which he derives a semi-empirical method for determining base drag by drawing an analogy between the flow over a two-dimensional base and the peak pressure rise associated with boundary layer separation in flow over a two-dimensional forward facing step. The analogy is extended to bodies of revolution, and can be applied to cylindrical and boat-tailed bases in the Mach number range 1·0 to 8·0, although the experimental data used extend only to $M=4{\cdot}0$. It is shown that for a turbulent boundary layer Reynolds number effects are small. The effects of fins, fore-body and angle of attack are also covered.

An accurate quantitative method for determining base drag in the presence of a jet has yet to be found; however, Cortright[7] has shown how useful the peak pressure rise analogy can be in estimating trends of such effects as those due to jet separation and base diameter/nozzle diameter ratio.

Long Tom has a convergent-divergent nozzle of exit-to-throat area ratio of approximately 5. When such a nozzle is operating at its optimum design point, the static pressure at the nozzle exit p_j is equal to the free stream static pressure p_∞ and the base pressure would be much the same as in the motor-off case, but acting only over the annulus surrounding the jet exit. Hence the base drag would be reduced by a factor

$$\frac{\text{area of annulus}}{\text{total area of base}}.$$

The ratio of base pressure p_b to free stream static pressure p_∞ is a function both of jet static pressure ratio p_j/p_∞ and the ratio of base diameter D_B to nozzle diameter D_N. When $p_j/p_\infty=1$, as above, the convergent-divergent nozzle is fully expanded.

The chamber pressures in the Mayfly motors employed in both stages of Long Tom are such that at sea level p_j/p_∞ is of the order of 2 and in the region of 40,000 ft., when second ignition occurs p_j/p_∞ is of the order of 10; the nozzles are under-expanded during both burning phases.

Cortright[7] has calculated the ratio of base pressure p_b to free stream static pressure p_∞ as a function of jet static pressure ratio p_j/p_∞ and D_B/D_N. The configuration he considered was a convergent nozzle fitted in an afterbody with 5·6° boat-tail, operating at a Mach number of 1·9. Since the boat-tail angle and the free stream Mach number will affect the pressures in the external flow, this must affect the base pressure ratio for a given p_j/p_∞, hence Cortright's curves are not strictly applicable to Long Tom which has a cylindrical afterbody. The flow characteristics of the convergent nozzle

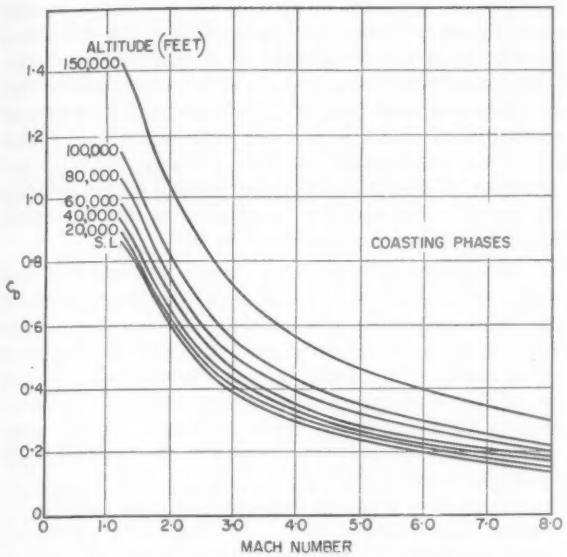


FIGURE 10. Long Tom and Aeolus drag coefficient for second-stage coasting.

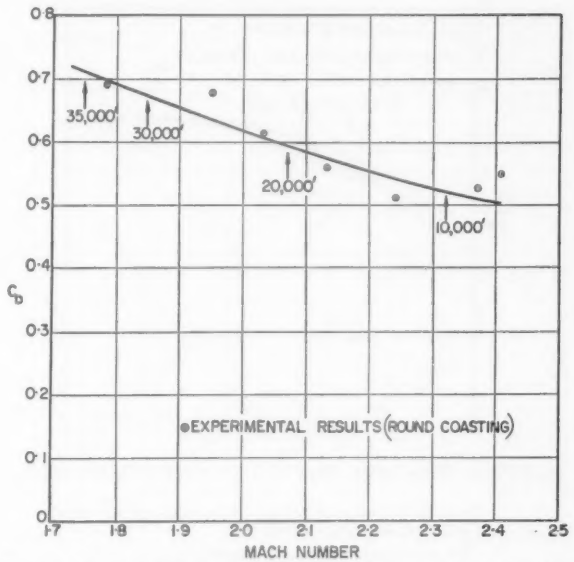


FIGURE 11. Comparison between drag estimates and trial results.

are also somewhat different from the convergent-divergent nozzle of Long Tom, but the effect of this is small. However, using these curves as a guide it was concluded that during first burning, when p_1/p_∞ is of the order of 2, the drag coefficient C_{D_B} (referred to body cross-sectional area) due to pressure on the base annulus would be about one quarter the value of C_{D_B} (referred to the same area) when the motor was not burning and the whole base area was contributing to base drag. During second burning the C_{D_B} with motor on would be sensibly zero.

In view of the fact that during burning the thrust is large compared with the drag, any base drag effects on this configuration would be swamped by uncertainties in thrust prediction, so base drag was taken as zero during both thrusting phases. In other cases, where jet exit diameter is small compared with base diameter, the base drag during thrusting can exceed the coasting value. The overall drag coefficient computed for the Long Tom second stage during coasting is shown as a function of Mach number and altitude in Fig. 10. These curves apply also to Aeolus. A check on the accuracy of these drag estimates was made after the initial firing of Long Tom. The experimental points in Fig. 11 were derived from the trajectory data; the full line was derived by using the theoretical curves of Fig. 10 in conjunction with height and Mach number data from the trial. The agreement shown between the experimental points and the estimated line in Fig. 11 is sufficiently good for general performance estimates.

3. Static Stability

Having obtained the likely Mach number range from the still-air performance estimates, it must be ascertained that the rocket has adequate static stability over all the flight phases. Static margin is here expressed as the distance the resultant centre of pressure (c.p.) lies behind the centre of gravity (c.g.). The criterion adopted is that for adequate static stability the static margin should not be less than 5 per cent of the body length. The initial position of the c.g. is a function of the initial weight of the round and, since the instrument compartment is at the forward end of the round, the c.g. is farthest aft when the round is in its condition of least loading. As the motor burns the c.g. moves forward some six inches. A lightly loaded round, of course, achieves a high Mach number and fin power deteriorates with increase in Mach number; the combination of high Mach number, lower fin power and aft c.g. position tends to make the low loading cases critical as far as static stability is concerned.

The c.p. position $X_{c.p.}$ of the fin-body combination is determined from the relation

$$X_{c.p.} = \frac{\left(\frac{dC_n}{d\alpha}\right)_{body}(x_{c.p.})_{body} + \left(\frac{dC_n}{d\alpha}\right)_{fins}(x_{c.p.})_{fins}}{\left(\frac{dC_n}{d\alpha}\right)_{body} + \left(\frac{dC_n}{d\alpha}\right)_{fins}}$$

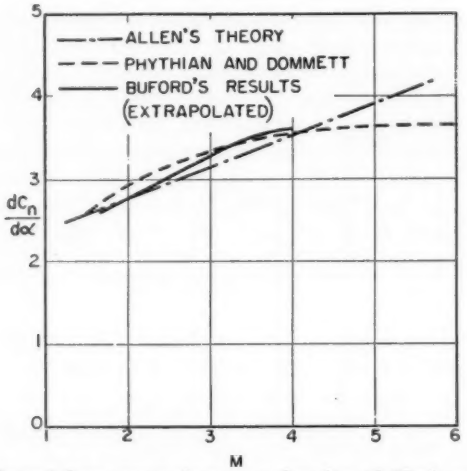
where $\left(\frac{dC_n}{d\alpha}\right)_{body}$ is the slope of the normal force curve at zero incidence of the body alone.

$\left(\frac{dC_n}{d\alpha}\right)_{fins}$ is the slope of the normal force curve at zero incidence of the isolated fins, adjusted for fin body interference.

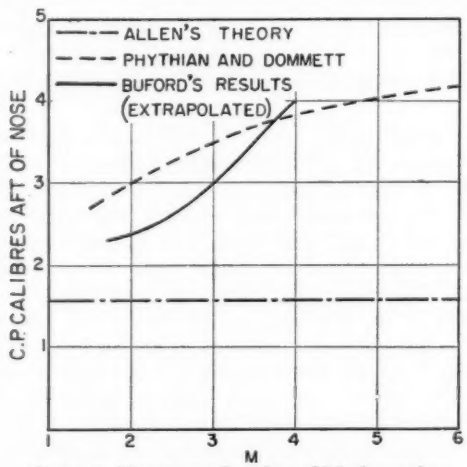
$(x_{c.p.})_{body}$ is the distance of c.p. of the body alone from the tip of the nose cone.

$(x_{c.p.})_{fins}$ is the distance of the fin c.p. from the tip of the nose cone adjusted for fin body interference.

The interference effects considered are the effective increase in fin normal force due to the upwash field created by the body at incidence, and the modification



(*a*) Normal force curve slope as a function of Mach number.



(*b*) c.p. (calibres) as a function of Mach number.

FIGURE 12. Normal force and centre of pressure of a 10° cone-cylinder. Overall fineness ratio 20, nose fineness ratio 2·8.

of body lift due to the Mach cones originating at the fin leading edge roots. Both these effects are combined as a factor on the isolated fin normal force curve slope and on the isolated fin c.p. position.

The method of allowing for fin-body effects follows closely that given by Pitts, Nielsen and Kaattari[8], although other methods are used for computing the lift curve slopes and c.p. positions of the isolated fins and bodies.

A semi-empirical method based on Allen's theory[9] had been used in estimating the body c.p. position at low supersonic Mach numbers but it was found that this failed to predict any rearward shift of body c.p. with increase in Mach number, and resulted in an undesirable restriction on the limit of permissible c.g. position and hence, on the minimum loading. Some recent work by Buford[10] indicated that the body normal force curve slope might be expected to decrease beyond a Mach number of about 3 or 4, accompanied by a slight rearward shift of the body c.p.; both these effects alleviate the stability problem at high Mach numbers. Slender body theory attributes no lifting effect to the cylindrical after-body of a cone cylinder at or near zero incidence, while calculations based on the shock expansion method of Syvertson and Dennis[11] indicate a lift carry-over effect round the shoulder of the cone cylinder. A review of current information has been made by Phythian and Dommett[12] who present semi-empirical curves enabling forces on cone cylinder combinations to be readily estimated at Mach numbers up to 6.

Buford's experimental results are confined to a nose semi-vertex angle of 10° and since cone angle is one of the most important parameters governing flow conditions at the shoulder, they are not readily applicable to other cases. The normal force curve slope and position for a 10° cone cylinder of fineness ratio 20 (approximating to Long Tom) were computed by the semi-empirical slender body theory and by the semi-empirical method of Phythian and Dommett. The results are compared with Buford's experimental results in Fig. 12. Buford's results extend only to a fineness ratio of 14 and it was necessary to extrapolate them somewhat. It will be seen in Fig. 12(*a*) that above a Mach number of 4 slender body theory would tend to over-estimate normal force curve slope. The agreement between Phythian and Dommett's method and Buford's experimental results is good. In the case of centre of pressure position, Fig. 12(*b*) shows that the constant c.p. given by slender body theory is too far forward over the whole Mach number range considered. The comparison between Phythian and Dommett's method and Buford's results is not so good as in the case of normal force curve slope, but the difference is not greater than 0·6 calibre at Mach numbers below 4. Beyond this, the trend of the experimental (Buford's) curve is still of positive slope while Phythian and Dommett's curve tends to flatten out at a lower value. At the lower Mach numbers fin power is sufficiently high to provide adequate stability even if slender body theory is used for the body, but as the hypersonic region is approached fin power decreases fairly rapidly and it is then that body lift becomes significant. Fig. 12(*b*) would indicate that Phythian and Dommett's method gives a conservative estimate of body c.p. in the higher Mach number range and is adequately consistent with experimental data in the lower supersonic range ($1 < M < 4$).

The method of Ref. 12 was used to re-compute the static margin of the Long Tom second stage both before and after motor burning. At the end of burning of the second stage, Mach numbers between 5 and 7 can be achieved, and this is the most critical flight phase from the point of view of stability. In Fig. 13 static margin as a percentage of body length is shown for the second stage as a function of Mach number and c.g. position, expressed in calibres aft of the nose (1 calibre $=9{\cdot}2$ in.). The approximate c.g. positions during the final coasting phase are shown by dotted lines for second stage initial weights of 500 lb., 550 lb., 600 lb. and 700 lb. Fig. 14 shows the peak Mach number attained for the range of second stage weights. For weights below 550 lb. approximately, the round is likely to have a static

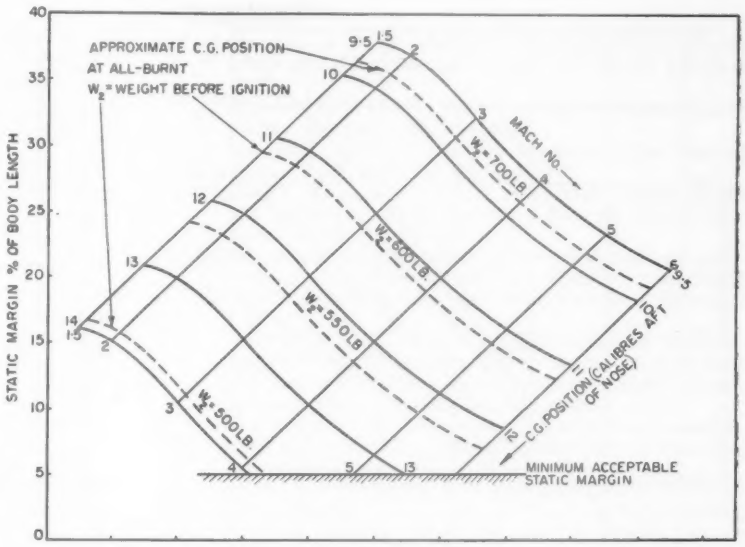

APPROXIMATE C.G. POSITION AT ALL-BURNT
W_2 = WEIGHT BEFORE IGNITION
MACH No.
W_2 = 700 LB
W_2 = 600 LB
W_2 = 550 LB
W_2 = 500 LB
STATIC MARGIN % OF BODY LENGTH
C.G. POSITION (CALIBRES AFT OF NOSE)
MINIMUM ACCEPTABLE STATIC MARGIN

FIGURE 13. Static margin of second stage as a function of centre of gravity and Mach number.

margin below the acceptable minimum of 5 per cent of body length in the final coasting period unless the payload can be so arranged to bring the c.g. forward.

4. The Effect of Weight and Launch Elevation on Performance

The preceding discussion on design considerations applies equally to both Long Tom and Aeolus. Long Tom is considered in detail in the following paragraphs on performance; Aeolus has a lower performance, the order of the comparison being indicated by Fig. 8.

4.1. THE EFFECT OF WEIGHT AND LAUNCH ELEVATION ON PERFORMANCE FOR LONG TOM

In a typical Long Tom round of all-up weight of the order of 2,000 lb. the boost stage weighs about 1,400 lb. and the second stage 600 lb. The weight of the boost stage does not alter significantly from round to round. The weight of the second stage can vary between 520 lb. and 700 lb., depending on the instrumentation carried.

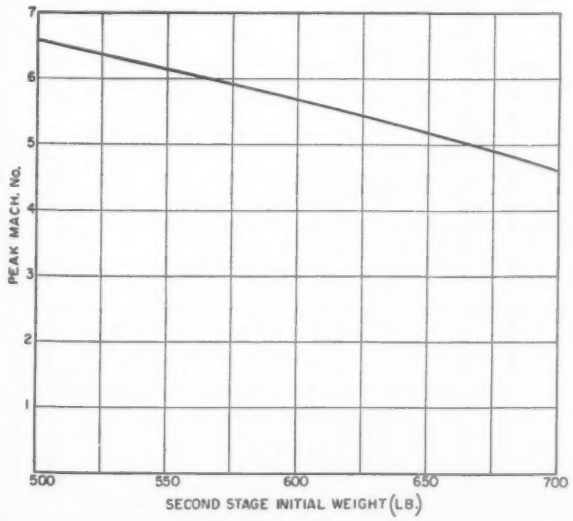


FIGURE 14. Variation of peak Mach number with second stage weight.

Thus the all-up weight of the second stage is the parameter to be considered when assessing the effect of weight on performance. In this section a constant second stage ignition time of 20 sec. and constant all-up weight of 1,400 lb. for the first stage have been assumed. In Fig. 15 peak altitude has been plotted as a function of the launch angle and initial weight of the second stage. The approximate payloads for each weight are indicated.

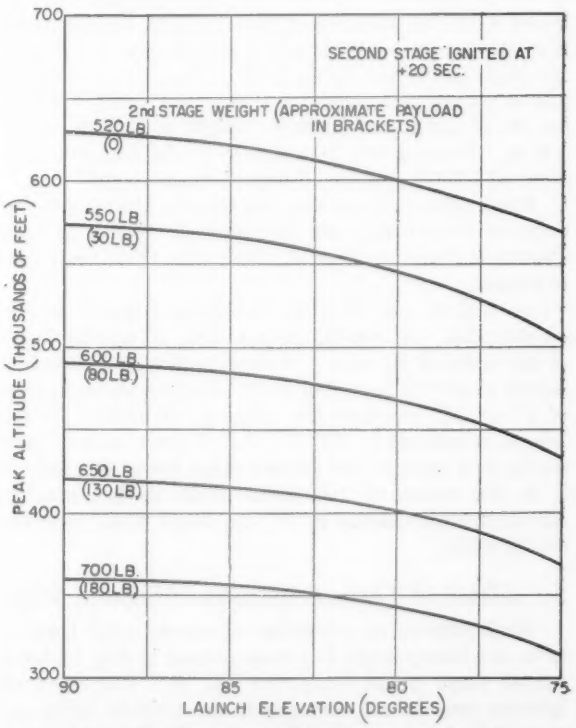

SECOND STAGE IGNITED AT +20 SEC.
2nd STAGE WEIGHT (APPROXIMATE PAYLOAD IN BRACKETS)
520 LB (0)
550 LB (30 LB.)
600 LB (80 LB.)
650 LB (130 LB.)
700 LB (180 LB.)
PEAK ALTITUDE (THOUSANDS OF FEET)
LAUNCH ELEVATION (DEGREES)

FIGURE 15. Long Tom. Peak altitude as a function of second stage weight and launch elevation.

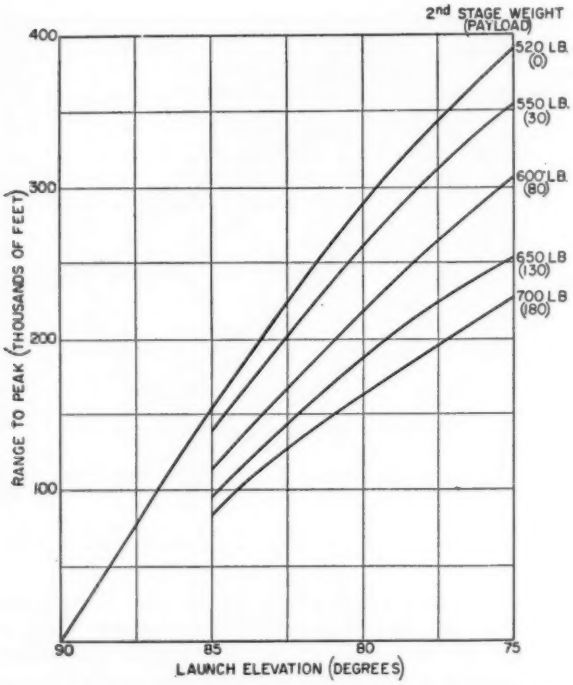


FIGURE 16. Long Tom. Range to peak altitude as a function of launch elevation and second stage weight.

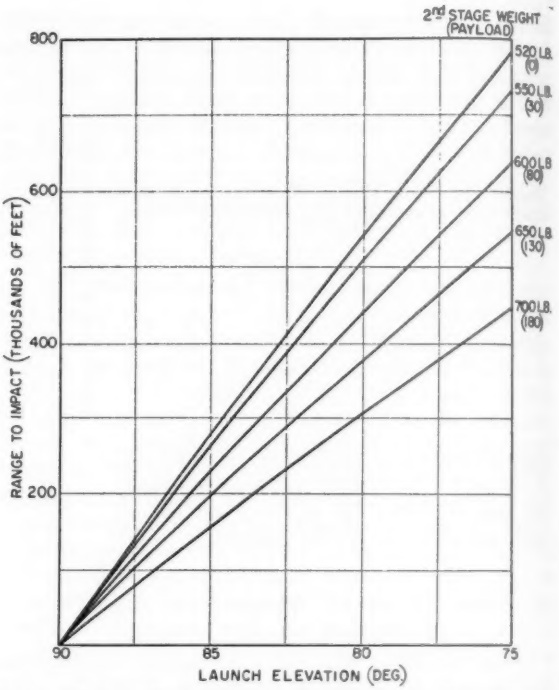


FIGURE 17. Long Tom. Range to impact as a function of launch elevation and second stage weight.

For the maximum weight considered, 700 lb., the peak altitude varies from 310,000 ft. at a launch angle of 75° to 360,000 ft. at 90°. It should be noticed that above 82·5° the increase of altitude with launch angle is small, but the peak altitude drops off more rapidly as the angle is lowered below 82·5°. The gain in altitude due to reduction in weight is substantial, being 1,600 ft. per lb. of initial second stage weight at weights below 600 lb. Between 600 lb. and 700 lb. the gain is of the order of 1,200 ft. per lb. of second stage weight.

For a typical round weighing 600 lb., altitudes of the order of 470,000 ft. could be expected. Range to peak altitude is shown in Fig. 16, while Fig. 17 shows range to impact.

As will be seen from Fig. 17 ground ranges can be considerable. A typical round with a second stage of the order of 40 miles. A drop in launcher elevation weight of 600 lb. launched at 85° covers a ground range of 5° to 80° increases the range to 80 miles. If the weight is reduced to 520 lb.—*i.e.* if the rocket is used purely as a sighter—the ground range for an 80° launch is in the region of 100 miles, while if the launcher elevation were reduced to 75° the range would increase to 150 miles.

5. Effect of Time of Ignition of Second Stage

Peak altitude as a function of second-stage ignition time and launch angle has been plotted in Fig. 18 for a second stage initial weight of 650 lb. The effect of ignition time is not very great, the altitude being increased by only some 25,000 ft. when the time of ignition is reduced from 25 sec. to 15 sec. Delaying the time of ignition beyond 25 sec. would result in an excessive decrease in performance; reducing it below 15 sec. would not result in any appreciable gain in peak altitude and would intensify the aerodynamic heating effects, due to the fact that the highest velocities are reached at lower altitudes. It has been the general practice at W.R.E. to ignite the second stage at +20 sec.

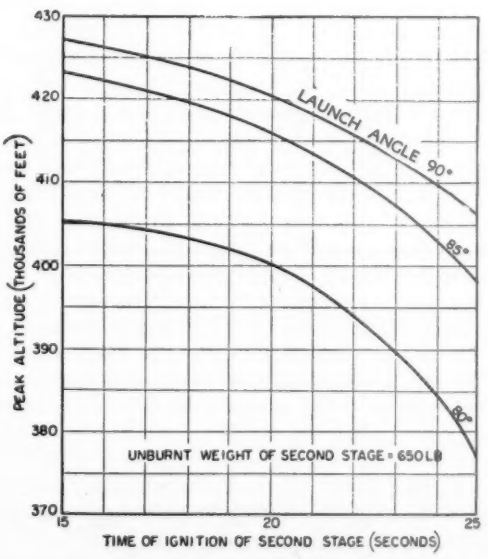


FIGURE 18. Peak altitude as a function of second-stage ignition time and launch angle.

6. Conclusions

The development of vehicles suitable for exercising and testing instrumentation at Woomera Range has resulted in the production of vehicles that are also suitable as sounding rockets for general experiments at altitudes up to about 100 miles. These two-stage vehicles (Long Tom and Aeolus), when compared with current single-stage sounding rockets of similar capabilities, have certain advantages as to ease of launching; the major disadvantage of the two-stage technique in this instance is the high longitudinal acceleration associated with short-burning, high-thrust solid fuel motors. At the end of burning of the second stage Long Tom has a peak acceleration in the region of 50*g*. However, the telemetry components, transducers, etc., that have been carried in Long Tom and Aeolus have operated adequately in this environment.

A logical development of Long Tom as a sounding rocket would be to extend the burning time of the first stage without changing the total impulse, shaping the thrust curve to keep the launch acceleration at a high value while reducing the in-flight acceleration, and hence the peak velocity and drag. This should result in a marked improvement in altitude performance. The type of thrust shaping required is quite possible with modern solid fuel motor design techniques.

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TECHNICAL NOTES

A Note on the Induced Drag of Jet-Flapped Wings

by

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THE MAIN PURPOSE of this note is to explain the apparent discrepancy which arises when the change in effective aspect ratio due to blowing, as predicted by the theoretically derived expression for the induced drag coefficient[1], is compared with what one intuitively expects from the general flow picture. If the jet sheet is considered as a chordwise extension of the wing (mechanical flap analogy), the general flow picture suggests that the effective aspect ratio of a wing without blowing is reduced by blowing. Maskell and Spence's[1] relation for the induced drag coefficient, however, indicates that the effect of jet blowing is to increase the effective aspect ratio.

In the two-dimensional case the jet sheet ultimately becomes parallel to the undisturbed main stream. By considering the horizontal flux of momentum across a plane at downstream infinity, the thrust force per unit span experienced by the wing is found to be equal to the jet momentum flux per unit span. However, in the three-dimensional case the jet remains deflected and the thrust experienced by the wing (T) is less than the total momentum flux (J_T) in the jet. Maskell and Spence define the difference between the two as the induced drag

$$D_i = J_T - T. \quad . \quad . \quad . \quad (1)$$

(It should be noted that equation (1) applies only for ideal flow.) To find the induced drag total lift relationship one has to determine the total lift (L_T) and the thrust (T).

Assume an elliptic spanwise load distribution (C_J and τ are constant along span) and that τ_∞, which is also constant along span, is small. The horizontal and vertical components of the jet momentum far behind the wing are then $J_T(1-\frac{1}{2}\tau_\infty^2)$ and $J_T\tau_\infty$. In order to get the total lift and the thrust, respective main stream contributions must be added. These contributions have been worked out by Maskell and Spence[1] and are given by:

$$\text{contribution to the total lift} = \frac{\pi}{4} b^2 \rho_0 V_0^2 \tau_\infty \quad . \quad (2a)$$

$$\text{contribution to the thrust} = -\frac{\pi}{8} b^2 \rho_0 V_0^2 \tau_\infty^2 \quad . \quad (2b)$$

where b is the span, ρ_0 and V_0 are free stream density and velocity and τ_∞ is the downwash angle at infinity downstream (*see* Fig. 1).

Therefore

$$L_T = J_T\tau_\infty + \frac{\pi}{4} b^2 \rho_0 V_0^2 \tau_\infty \quad . \quad . \quad (3)$$

$$T = J_T\left(1-\frac{1}{2}\tau_\infty^2\right) - \frac{\pi}{8} b^2 \rho_0 V_0^2 \tau_\infty^2 \quad . \quad . \quad (4)$$

and

$$D_i = J_T - T = \frac{1}{2}\tau_\infty^2\left(J_T + \frac{\pi}{4} b^2 \rho_0 V_0^2\right). \quad . \quad (5)$$

Dividing throughout by $\frac{1}{2}\rho_0 V_0^2 S_w$ we get:

$$C_{LT} = \frac{1}{2}\tau_\infty(\pi AR + 2C_J) \quad . \quad . \quad . \quad (3a)$$

$$C_{Di} = \frac{1}{4}\tau_\infty^2(\pi AR + 2C_J) \quad . \quad . \quad (5a)$$

where AR is the aspect ratio, equal to b^2/S_w. From equations (3a) and (5a) one obtains the expression for the induced drag as derived by Maskell and Spence:

$$C_{Di} = C_{LT}^2/(\pi AR + 2C_J) \quad . \quad . \quad (6)$$

or

$$C_{Di} = \frac{C_{LT}^2}{\pi AR\left[1+\dfrac{2C_J}{\pi AR}\right]} = \frac{C_{LT}^2}{\pi ARK} = \frac{C_{LT}^2}{\pi AR_E} \quad . \quad (7)$$

Equation (7) indicates that for increasing C_J values the

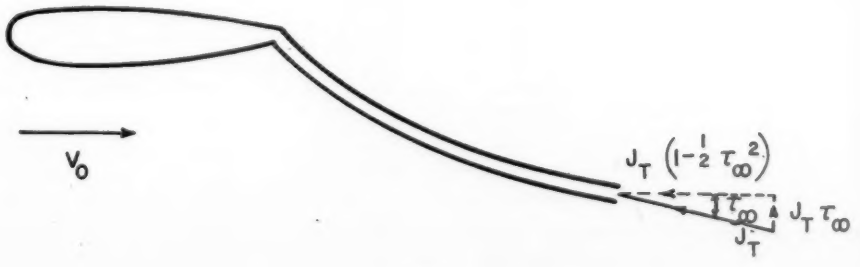

FIGURE 1. Momentum forces of a three-dimensional jet sheet.

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effective aspect ratio (AR_E) increases, which agrees with the experimental evidence, but contradicts what one would expect if the jet sheet is considered as a chordwise extension of the wing. Next it will be shown that this contradiction results from an improper choice of lift for this comparison.

In equation (7) the induced drag of a jet-flapped wing is related to the total lift which is the sum of the circulation lift (L_C) and the impulse lift ($J_T \sin \tau_\infty$). Imagine now that the jet sheet of this wing is replaced by vortex sheets or a chordwise extension (analogous mechanical flap) of the wing. It is known that such a wing can only produce circulation lift. To make a proper comparison, an expression for C_{Di} in terms of C_{LC} has to be derived. (We are indebted to Prof. B. Etkin for suggesting this idea.) From equation (3) it follows that

$$L_C = L_T - J_T \tau_\infty = \frac{\pi}{4} \rho_0 b^2 V_0^2 \tau_\infty \quad . \quad (8)$$

which in non-dimensional form is

$$C_{LC} = \frac{1}{2} \pi AR \tau_\infty \quad . \quad . \quad . \quad . \quad (9)$$

Rewriting equation (5*a*) as

$$C_{Di} = \frac{1}{4} \pi AR \tau_\infty^2 \left(1 + \frac{2C_J}{\pi AR}\right) \quad . \quad . \quad (10)$$

and combining it with equation (9), we get

$$C_{Di} = \frac{C_{LC}^2}{\pi AR \left[1 \Big/ \left(1 + \frac{2C_J}{\pi AR}\right)\right]} = \frac{C_{LC}^2}{\pi AR \frac{1}{K}} = \frac{C_{LC}^2}{\pi AR_E'} \quad (11)$$

Equation (11) indicates that the effective aspect ratio (AR_E') decreases with increasing C_J. This finding agrees with the expected result. The expression shows that no discrepancy results for the AR_E' change as predicted by either Maskell and Spence or the mechanical flap analogy method, provided that the circulation lift coefficient (C_{LC}) is used for this comparison.

The interpretation of equations (7) and (11) can be summarised as follows. Let C_L' and C_{Di}' denote the lift and the induced drag coefficients of a conventional wing. If we compare the jet-flapped wing with a conventional wing under the condition $C_L' = C_{LC}$ we get $C_{Di}' < C_{Di}$, *i.e.*, the effective aspect ratio of the jet-flapped wing is smaller than that of the conventional wing. However, a comparison under the condition $C_L' = C_{LT}$ furnishes $C_{Di}' > C_{Di}$, which means that the effective aspect ratio of the jet-flapped wing is greater than that of the conventional wing. This improved performance is due to the additional impulse lift term in C_{LT}. The experimental results, based on C_{LT}, verify the increase in effective aspect ratio, since the test results only reflect the total lift effect.

The induced drag can be obtained from either equation (7) or equation (11). However, equation (7) is the more practical one to use as C_{LT} is easier to obtain, both theoretically and experimentally. The circulation lift coefficient follows from $C_{LC} = C_{LT}/K$ if C_{LT} is known. An interesting expression for C_{Di} obtained from equations (7) and (11) is:

$$C_{Di} = \frac{C_{LT} C_{LC}}{\pi AR} \quad . \quad . \quad . \quad . \quad (12)$$

Next, let us derive the relationship between the circulation lift coefficient (C_{LC}) and the induced drag coefficient ($\overline{C}_{Di}$) as defined by Helmbold[2] for the three-dimensional jet-flapped wing. Helmbold's induced drag $\overline{D}_i$ is defined as

$$\overline{D}_i = D_i - J_T \frac{1}{2} \tau_\infty^2 \quad . \quad . \quad . \quad (13)$$

From equations (5) and (13) we get

$$\overline{D}_i = \frac{\pi}{8} \rho_0 b^2 V_0^2 \tau_\infty^2 \quad . \quad . \quad . \quad (14)$$

which written in non-dimensional form is

$$\overline{C}_{Di} = \frac{\pi}{4} AR \tau_\infty^2 \quad . \quad . \quad . \quad . \quad (14a)$$

From equations (9) and (14*a*) it follows that

$$\overline{C}_{Di} = \frac{C_{LC}^2}{\pi AR} \quad . \quad . \quad . \quad (15)$$

By combining equations (7), (11), and (15) the following relation is obtained

$$\frac{C_{Di}}{\overline{C}_{Di}} = \frac{C_{LT}}{C_{LC}} = K = \left(1 + \frac{2C_J}{\pi AR}\right) \quad . \quad (16)$$

Comparing[3] C_{Di} and $\overline{C}_{Di}$ as to their usefulness in practice, it can be said that C_{Di} is easier to determine, incorporates all finite aspect ratio effects and is better suited for the evaluation of balance measurements and the interpretation of the total drag.

It should be realised that the induced drag of a three-dimensional jet-flapped wing (D_i), defined as the drag resulting from the finiteness of the wing span, results from two sources. The first one ($\overline{D}_i$) is due to the inclination of the resultant pressure force on the wing-jet combination, which may be called the vortex drag. The second one, $J_T(1-\cos \tau_\infty)$, originates from the loss in thrust due to non-zero downwash angle at infinity ($\tau_\infty \neq 0$), which may be called the induced loss of thrust. So, we have

$$D_i = \overline{D}_i + J_T (1 - \cos \tau_\infty) \quad . \quad . \quad (17a)$$

i.e.,

induced drag = vortex drag + induced loss of thrust (17*b*)

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A Simplified Method for Estimating the Properties of Thin Aerofoils Influenced by Jet

by

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TO PREDICT the aerodynamical properties of a thin aerofoil, provided with a high velocity jet sheet in its trailing edge region, a simple procedure is proposed as follows. Two general separate cases concerned with the effect of a jet on an aerofoil are considered. In the first case, the jet is blown tangentially over the upper surface of the aerofoil, while in the second case, the jet is ejected at a deflection angle from the trailing edge. In this analysis a procedure which is similar to the classical Glauert treatment of thin aerofoils[1] is applied.

Consider first the special case of a thin aerofoil placed at zero incidence in a two-dimensional inviscid flow of velocity V_0, with a jet emerging with an exit velocity V_1 at distance x_1 from the leading edge and blown tangentially over the upper surface of the aerofoil (Fig. 1). It is assumed that an effectively attached flow may be obtained.

In a similar way as in the classical treatment[1] suppose that the aerofoil may be represented by a vortex distribution of strength $V_0 f(x)$ per unit length. On the basis of the assumptions of the potential theory, the virtual jet boundaries represent, in two-dimensional flow, the lines of discontinuity in velocity which may be similarly replaced by vortex sheets. The local strength $V_0 g(x)$ of these vortices may be considered as proportional to the difference of velocities just inside and just outside the virtual boundary, so that

$$V_0 g(x) = k(V - V_0) \quad . \quad , \quad . \quad (1)$$

where k is a proportionality jet shape factor.

In a real jet, the mixing with the surrounding air flow occurs. Considering this mixing effect, in an earlier treatment[2] it has been shown that a real jet may be to a first order adequately replaced by an appropriate aerodynamical model suitable to simple calculation, having a length s and a linear distribution of velocity determined by

$$\frac{V - V_0}{V_0} = \frac{g(x)}{k} = \frac{g_2}{k}(x_1 + s - x). \quad . \quad . \quad (2)$$

On the basis of numerous experimental results, it was assumed that

$$\frac{g_2}{k} = \frac{1-\lambda}{\lambda} \cdot \frac{1-(2-\lambda)\lambda^2}{20\lambda^2 c_J} \quad . \quad . \quad (3)$$

and

$$s = \frac{10\lambda^2 c_J}{1-(2-\lambda)\lambda^2} \quad . \quad . \quad . \quad . \quad (4)$$

where $\lambda = V_0/V_1$ is the ratio of the undisturbed external air flow velocity to the jet exit velocity,

$$c_J = \frac{J}{\frac{1}{2}\rho_0 V_0^2} \quad . \quad . \quad . \quad . \quad (5)$$

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is the jet momentum-flux coefficient, where J is the flux of momentum and ρ_0 is the density of external air flow.

The velocity at any point x_0 of the aerofoil is the resultant of the free-stream velocity V_0 and the velocities

$$w = \frac{V_0}{2\pi} \int \frac{f(x)}{x - x_0}\, dx \quad . \quad . \quad (6)$$

and

$$w_J = \frac{V_0}{2\pi} \int \frac{g(x)}{x - x_0}\, dx \quad . \quad . \quad . \quad (7)$$

induced by the vortex distributions $V_0 f(x)$ and $V_0 g(x)$, representing the aerofoil and the jet sheet, respectively.

The direction of the resultant velocity adjacent to the aerofoil must be parallel to the surface and so, at each point of the aerofoil, at zero incidence

$$\frac{dy}{dx} = \frac{w}{V_0} + \frac{w_J}{V_0} = 0. \quad . \quad . \quad . \quad (8)$$

Introducing a new co-ordinate θ defined by

$$x = \frac{1}{2}(1 + \cos\theta) \quad . \quad . \quad . \quad (9)$$

and writing

$$V_0 f(x) = 2V_0 \left(A_0 \tan\frac{\theta}{2} + \sum_1^\infty A_n \sin n\theta\right) \quad . \quad (10)$$

we obtain

$$\frac{w}{V_0} = -A_0 - \sum_1^\infty A_n \cos n\theta. \quad . \quad . \quad (11)$$

When assuming that the main flow around the aerofoil does not influence the velocity distribution in the jet, it is found by substituting equations (2) and (9) into equation (7) and integrating

$$\frac{w_J}{V_0} = \frac{g_2}{4\pi}\left\{[2x_1 + 2s - (1+\cos\theta)]\log\left|\frac{2x_1 + 2s - (1+\cos\theta)}{2x_1 - (1+\cos\theta)}\right| - 2s\right\} \quad . \quad . \quad . \quad (12)$$

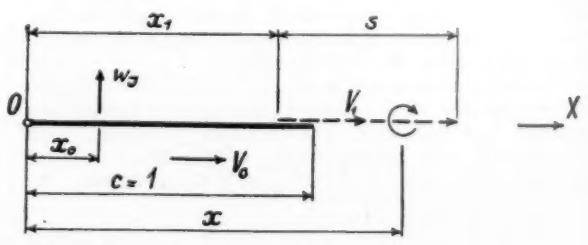

FIGURE 1.

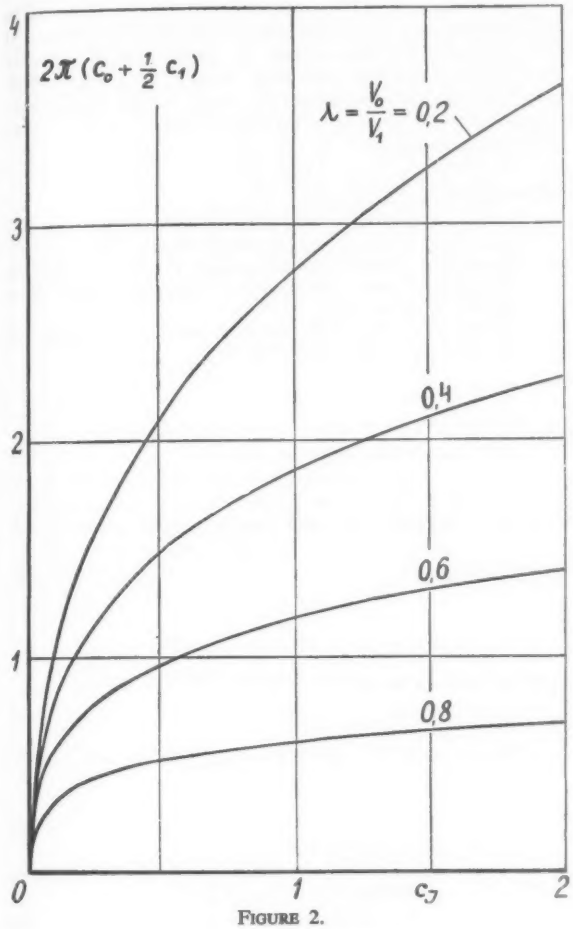

FIGURE 2.

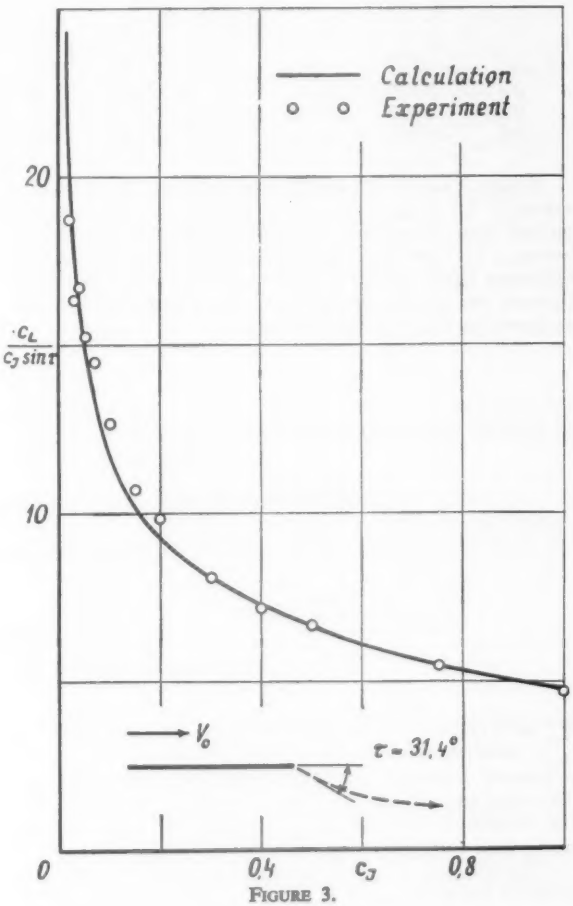

FIGURE 3.

From equations (8) and (11) we obtain

$$-A_0-\sum_1^{\infty}A_n\cos n\theta+\frac{w_J}{V_0}=0 \quad . \quad . \quad (13)$$

where

$$A_0=\frac{1}{\pi}\int_0^{\pi}\frac{w_J}{V_0}d\theta \quad . \quad . \quad (14)$$

and

$$A_n=\frac{2}{\pi}\int_0^{\pi}\frac{w_J}{V_0}\cos n\theta d\theta. \quad . \quad . \quad (15)$$

These equations are sufficient to determine the lift and the pitching moment about leading edge of thin aerofoil influenced by the jet, in terms of the coefficients A_0 and A_n.

For a jet blown tangentially over the upper surface of an aerofoil at zero incidence (Fig. 1), the total lift and pitching moment ccefficients as obtained by such a procedure are

$$c_L=2\pi k\left(c_0+\frac{1}{2}c_1\right) \quad . \quad . \quad (16)$$

$$c_m=-\frac{\pi}{2}k\left(c_0+c_1-\frac{1}{2}c_2\right) \quad . \quad (17)$$

where $c_0=\frac{A_0}{k}$, $c_1=\frac{A_1}{k}$ and $c_2=\frac{A_2}{k}$. (18)

The value of the proportionality factor k, defined by equation (1), depends essentially on the angle at which the virtual jet boundary is inclined to the external undisturbed air flow.

In the earlier treatment[2] it is suggested to assume, in this case

$$k=\left(2-\frac{1-x_1}{s}\right)\frac{1-x_1}{s} \quad . \quad , \quad . \quad (19)$$

For a jet emerging at a deflection angle τ from the trailing edge of a thin aerofoil at zero incidence, one may assume $k=\tau$. In this case one obtains

$$c_L=2\pi\left(c_0+\frac{1}{2}c_1\right)\tau+c_J\sin\tau \quad . \quad (20)$$

$$c_m=-\frac{\pi}{2}\left(c_0+c_1-\frac{1}{2}c_2\right)\tau-c_J\sin\tau \quad . \quad (21)$$

where the last term $c_J\sin\tau$ represents the vertical component of the jet thrust.

The computed curves of values $2\pi\,(c_0+\frac{1}{2}c_1)$, for $x_1=1$, *i.e.* jet emerging from the trailing edge, and for representative values of c_J and λ are plotted against c_J in Fig. 2. Their numerical values are given in Table I.

TABLE I
COMPUTED VALUES OF $2\pi\,(c_0+\frac{1}{2}c_1)$

	$c_J=0{\cdot}1$	0·3	0·5	1·0	2·0
$\lambda=0{\cdot}2$	1·028	1·688	2·111	2·788	3·630
0·4	0·787	1·221	1·472	1·859	2·286
0·6	0·571	0·827	0·967	1·172	1·385
0·8	0·335	0·454	0·515	0·590	0·690

Figure 3 shows the comparison between the calculated values of lift magnification factor $c_L/c_J \sin\tau$, and experimental values taken from Ref. 3, obtained with an aerofoil having a 12·5 per cent thick elliptical cross section at a jet deflection angle $\tau=31{\cdot}4°$. It is believed that the agreement between the calculated curve and the experimental points as shown in Fig. 3 is encouraging.

The procedure briefly outlined in this note is limited to the simplest case of a thin aerofoil at zero incidence. It was extended by the author to more general cases of aerofoils at incidence and with hinged flaps, where both cases in which the jet enters the main stream tangentially from a deflected flap, or at an efflux angle from the trailing edge, are considered.

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Elementary Stress Analysis of Circular Frames in a Cylinder Partially Filled with Fluid

by

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EXPRESSIONS ARE FOUND and curves given for the bending moment, direct force and shear force around a circular frame, in a cylinder partially filled with fluid. The maximum bending moment is found to occur when the cylinder is half full, and its position to be at the level of the fluid surface.

The analysis is an elementary one, that is, engineer's bending theory is assumed to hold in the cylinder. Hence the resultant pressure of fluid on the frame is balanced by a sinusoidal varying shear flow around the frame.

INTRODUCTION

The Royal Aeronautical Society Data Sheets give graphs showing the bending moment, direct force and shear force around a circular frame when loaded by a concentrated moment or concentrated load. These graphs can be combined to give different combinations of loading.

However, it would seem to the author that there is at least one other "standard case" which it would be useful to have in data sheet form. That is the case of a circular frame loaded by fluid pressure, *i.e.* where the pressure increases linearly with the depth below the surface of the fluid. This, along with the concentrated force cases, would enable, for example, loading cases involving fuel pressures to be investigated.

The analysis used in this paper does not include any allowance for frame flexibility, *i.e.* it has been assumed that the shear stresses in the cylinder are distributed in accordance with engineer's bending theory. It can, of course, rightly be argued that this distribution is not correct close to the loaded frame, especially as we are dealing with a shell structure. However, an elementary analysis is still useful, particularly for initial design purposes, since at this stage there is not available either the detailed information required, or the time, for a more exact solution.

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NOTATION

R radius of frame (in.)
ϕ, θ angular distance measured clockwise from top centre line
α angular distance defining the level of the fluid
M_θ bending moment in the frame at position θ, positive if it produces tension on the inside of the frame (lb. in.)
T_θ direct load in the frame at position θ, positive if it produces tension (lb.)
S_θ shear load in the frame at position θ, positive if acting outwards on the clockwise side of the reference section (lb.)
σ "effective" density of fluid, *i.e.* (density) × (acceleration factor) (lb./in.^{3})
L width of the fluid considered to be acting on the frame, *e.g.* the pitch of the frames (in.)
$w=\sigma \times L$ (lb./in.^{2})

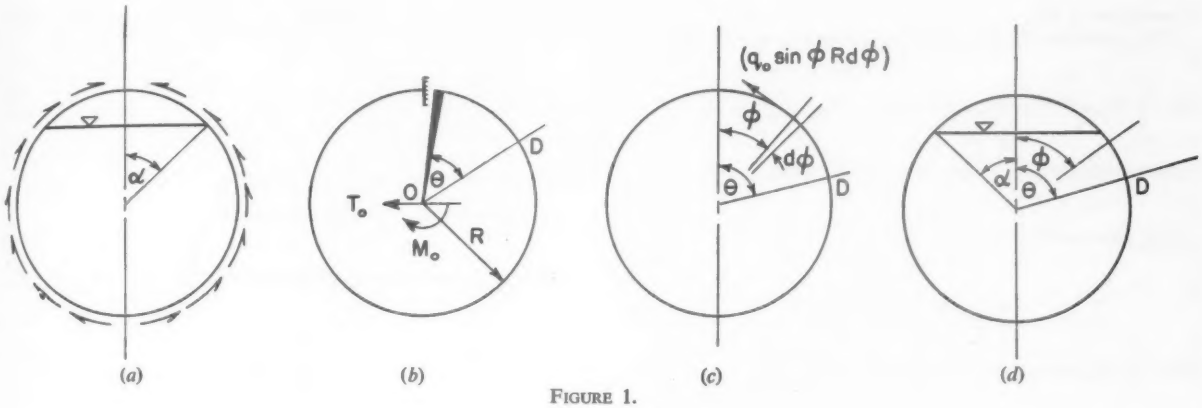
ANALYSIS

General

Consider a circular frame of constant bending stiffness EI and radius R, subjected to a fluid pressure as shown in Fig. 1(*a*). The resultant component of this pressure is, of course, the weight of the fluid and this is balanced by shear from the cylinder around the frame.

If the "elastic centre" method is chosen for the analysis then the origin is at O, the centre of the frame (Fig. 1(*b*)). There are three redundants but by symmetry there is no shear force at the top (or bottom) centre line, so we have only two unknowns and we can write the bending moment at position θ as

$$M=M_0+T_0R\cos\theta+M_{w\theta} \quad . \quad . \quad (1)$$



(a) (b) (c) (d)

FIGURE 1.

where M_0 is the unknown bending moment at origin O, T_0 is the unknown horizontal force at origin O, and $M_{w\theta}$ is the bending moment due to the external loading on the frame acting alone (" free " bending moment).

Since the external loading is fluid pressures and skin shears only we can write

$$M_{w\theta} = {}_1M_{w\theta} + {}_2M_{w\theta} \quad . \quad . \quad . \quad (2)$$

where ${}_1M_{w\theta}$ = bending moment due to fluid pressure alone
${}_2M_{w\theta}$ = bending moment due to skin shears alone.

Now ignoring all energy other than bending energy:—

$$\text{Strain Energy} = \frac{1}{2}\int \frac{M^2}{EI}\,ds = \frac{1}{2}\int \frac{M^2}{EI}\,Rd\theta$$

and so, by the Principle of Least Work

$$\left.\begin{aligned} \int_0^{\pi} \frac{M}{EI}\frac{\partial M}{\partial M_0}\,Rd\theta = 0 \\ \int_0^{\pi} \frac{M}{EI}\frac{\partial M}{\partial T_0}\,Rd\theta = 0 \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad (3)$$

Substituting equation (1) into equation (3) gives

$$M_0 = -\frac{1}{\pi}\int_0^{\pi} M_{w\theta}\,d\theta \quad . \quad . \quad . \quad . \quad (4)$$

and

$$T_0 = -\frac{2}{\pi R}\int_0^{\pi} M_{w\theta}\cos\theta\,d\theta \quad . \quad . \quad (5)$$

Reacting Shear Flow

From Fig. 1(*a*), the cross sectional area of fluid is:—

$$\pi R^2\left[1 - \frac{\alpha}{\pi} + \frac{\sin 2\alpha}{2\pi}\right]$$

and hence the weight of fluid to be supported by shear around the frame is:

$$w\pi R^2\left[1 - \frac{\alpha}{\pi} + \frac{\sin 2\alpha}{2\pi}\right].$$

The distribution of shear will be sinusoidal if we assume engineer's bending theory to hold in the supporting cylinder. Then the vertical component of the force on the element $Rd\phi$ is (Fig. 1(*c*))

$$q_0 \sin\phi Rd\phi \sin\phi$$

where q_0 is the maximum shear flow occurring at the horizontal centre line. Hence total vertical force due to shear is

$$2\int_0^{\pi} q_0 R\sin^2\phi\,d\phi = \pi R q_0.$$

Thus for vertical equilibrium

$$q_0 = wR\left[1 - \frac{\alpha}{\pi} + \frac{\sin 2\alpha}{2\pi}\right] \quad . \quad . \quad (6)$$

Free bending moment due to pressure, ${}_1M_{w\theta}$

Consider Fig. 1(*d*); the pressure at position ϕ is 0 if $\phi \leqslant \alpha$ and $wR\,[\cos\alpha - \cos\phi]$, if $\phi \geqslant \alpha$.

The bending moment at θ, ${}_1M_{w\theta}$, will be zero if $\theta \leqslant \alpha$. When $\theta \geqslant \alpha$ then the bending moment at θ due to the pressure loading at ϕ on element $Rd\phi$ is:

$$wR\,[\cos\alpha - \cos\phi]\,Rd\phi R\sin(\theta - \phi)$$

or
$${}_1M_{w\theta} = \int_{\alpha}^{\theta} wR^3(\cos\alpha - \cos\phi)\sin(\theta - \phi)\,d\phi$$

so

$$\frac{{}_1M_{w\theta}}{wR} = \cos\alpha - \left[1 - \frac{\sin^2\alpha}{2}\right]\cos\theta - \left[\frac{\sin 2\alpha}{4} + \frac{\theta}{2} - \frac{\alpha}{2}\right]\sin\theta \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

Free bending moment due to shear flow, ${}_2M_{w\theta}$

Consider Fig. 1(*c*); the bending moment at D, due to force on element at ϕ

$$= -q_0 \sin\phi Rd\phi R\,[1 - \cos(\theta - \phi)].$$

Hence

$${}_2M_{w\theta} = -\int_0^{\theta} q_0 R^2 \sin\phi\,[1 - \cos(\theta - \phi)]\,d\phi$$

so
$${}_2M_{w\theta} = q_0 R^2\left[\cos\theta - 1 + \frac{\theta}{2}\sin\theta\right] \quad . \quad . \quad (8)$$

Substituting equation (6) into equation (8) gives

$$\frac{{}_2M_{w\theta}}{wR^3} = \left[1 - \frac{\alpha}{\pi} + \frac{\sin 2\alpha}{2\pi}\right]\left[\cos\theta + \frac{\theta}{2}\sin\theta - 1\right] \quad . \quad . \quad (9)$$

Evaluation of M_0

To evaluate M_0 the following quantities are needed:—

(*a*) $\int_0^{\pi} {}_1M_{w\theta}d\theta = \int_{\alpha}^{\pi} {}_1M_{w\theta}d\theta$ because ${}_1M_{w\theta}=0$ for $0 \leqslant \theta \leqslant \alpha$.

Substituting for ${}_1M_{w\theta}$ from equation (7) gives

$$\int_0^{\pi} {}_1M_{w\theta}d\theta = \pi wR^3\left[\cos\alpha - \frac{\sin 2\alpha}{4} + \frac{\alpha}{2\pi} - \frac{1}{2} - \frac{\alpha}{\pi}\cos\alpha + \frac{\sin\alpha}{\pi}\right] \quad . \quad . \quad . \quad (10)$$

(*b*) $$\int_0^{\pi} {}_2M_{w\theta}d\theta = \pi wR^3\left[-\frac{1}{2} + \frac{\alpha}{2\pi} - \frac{\sin 2\alpha}{4\pi}\right] \quad . \quad . \quad (11)$$

when equation (9) is used.

Then from equations (2) and (4)

$$M_0 = -\frac{1}{\pi}\left[\int_0^{\pi} {}_1M_{w\theta}d\theta + \int_0^{\pi} {}_2M_{w\theta}d\theta\right]$$

$$= -\frac{1}{\pi}\left[\text{equation (10)} + \text{equation (11)}\right]$$

or

$$\frac{M_0}{wR^3} = -(1-\cos\alpha)\left[\frac{\sin\alpha}{\pi} + \frac{\alpha}{\pi} - 1\right] \quad . \quad . \quad (12)$$

Evaluation of T_0

The integrals to be evaluated in this case are

$$\int_0^{\pi} {}_1M_{w\theta}\cos\theta d\theta \text{ and } \int_0^{\pi} {}_2M_{w\theta}\cos\theta d\theta$$

whence using equation (5)

$$\frac{T_0}{wR^2} = \left[\frac{U}{2\pi} - \frac{1}{2}\right]\sin^2\alpha \quad . \quad . \quad (13)$$

General expressions for bending moment

Substituting equations (7), (9), (12) and (13) into equation (1) gives the following equations for bending moment

$0 \leqslant \theta \leqslant \alpha$

$${}_1m_\theta = \frac{M_\theta}{wR^3} = {}_1A_M + {}_1B_M\cos\theta + {}_1C_M\frac{\theta}{2}\sin\theta \quad . \quad (14)$$

$\alpha \leqslant \theta \leqslant \pi$

$${}_1m_\theta = \frac{M_\theta}{wR^3} = {}_2A_M + {}_2B_M\cos\theta + {}_2C_M\frac{\theta}{2}\sin\theta + {}_2D_M\sin\theta \quad . \quad . \quad . \quad (15)$$

where the coefficients *A*, *B*, *C*, and so on are dependent on the depth of fluid in the cylinder, so are functions of α.

$${}_1A_M = \left[-\frac{\sin\alpha}{\pi} - \left(1-\frac{\alpha}{\pi}\right)\cos\alpha\right];$$

$${}_2A_M = \left[-\frac{\sin\alpha}{\pi} + \frac{\alpha}{\pi}\cos\alpha\right]$$

$${}_1B_M = \left[\left(1-\frac{\alpha}{\pi}\right)\left(1-\frac{\sin^2\alpha}{2}\right) + \frac{\sin 2\alpha}{2\pi}\right];$$

$${}_2B_M = \left[-\frac{\alpha}{\pi}\left(1-\frac{\sin^2\alpha}{2}\right) + \frac{\sin 2\alpha}{2\pi}\right]$$

$${}_1C_M = \left[\left(1-\frac{\alpha}{\pi}\right) + \frac{\sin 2\alpha}{2\pi}\right]; \quad {}_2C_M = \left[-\frac{\alpha}{\pi} + \frac{\sin 2\alpha}{2\pi}\right]$$

$${}_2D_M = \left[\frac{\alpha}{2} - \frac{\sin 2\alpha}{4}\right]$$

General expressions for direct force

Consideration of Fig. 1(*b*) yields

$$T_\theta = T_0\cos\theta + \int_0^{\theta} q_0\sin\phi R d\phi\cos(\theta-\phi) + \int_{\alpha}^{\theta} wR\left[\cos\alpha - \cos\phi\right]Rd\phi\sin(\theta-\phi)$$

where the third term is only included when $\theta \geqslant \alpha$.

Evaluation of these integrals and substitution for T_0 from equation (13) gives the following expressions for direct force:—

$0 \leqslant \theta \leqslant \alpha$

$${}_1t_\theta = \frac{T_\theta}{wR^2} = {}_1B_T\cos\theta + {}_1C_T\frac{\theta}{2}\sin\theta \quad . \quad . \quad . \quad (16)$$

$\alpha \leqslant \theta \leqslant \pi$

$${}_2t_\theta = {}_2A_T + {}_2B_T\cos\theta + {}_2C_T\frac{\theta}{2}\sin\theta + {}_2D_T\sin\theta \quad . \quad . \quad (17)$$

where:—

$${}_2A_T = \cos\alpha; \quad {}_1C_T = {}_1C_M; \quad {}_2C_T = {}_2C_M; \quad {}_2D_T = {}_2D_M$$

$${}_1B_T = \left[-\left(1-\frac{\alpha}{\pi}\right)\frac{\sin^2\alpha}{2}\right]; \quad {}_2B_T = \left[-1+\frac{\alpha}{\pi}\frac{\sin^2\alpha}{2}\right].$$

General expressions for shear force

$$S_\theta = T_0\sin\theta + \int_0^{\theta} q_0\sin\phi R d\phi\sin(\theta-\phi) - \int_{\alpha}^{\theta} wR\left[\cos\alpha - \cos\phi\right]Rd\phi\cos(\theta-\phi)$$

where the third term is only included when $\theta \geqslant \alpha$.

Evaluating gives:

$0 \leqslant \theta \leqslant \alpha$

$${}_1s_\theta = \frac{S_\theta}{wR^2} = {}_1D_s\sin\theta + {}_1E_s\frac{\theta}{2}\cos\theta \quad . \quad . \quad . \quad (18)$$

$\alpha \leqslant \theta \leqslant \pi$

$${}_2s_\theta = {}_2B_s\cos\theta + {}_2D_s\sin\theta + {}_2E_s\frac{\theta}{2}\cos\theta \quad . \quad . \quad . \quad (19)$$

where:—

$${}_2B_s = -{}_2D_M; \quad {}_1E_s = -{}_1C_M; \quad {}_2E_s = -{}_2C_M;$$

$${}_1D_s = \left[\left(1-\frac{\alpha}{\pi}\right)\frac{\cos^2\alpha}{2} + \frac{\sin 2\alpha}{4\pi}\right];$$

$${}_2D_s = \left[-\frac{\alpha}{\pi}\frac{\cos^2\alpha}{2} + \frac{\sin 2\alpha}{4\pi}\right]$$

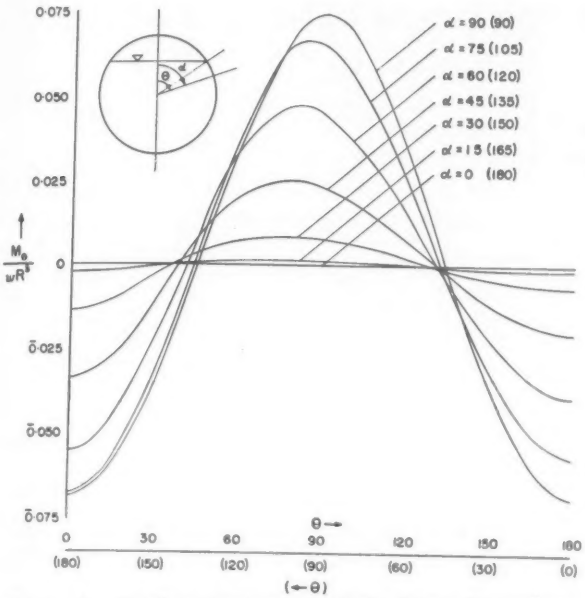


FIGURE 2. Bending moment around the frame for various depths of fluid.

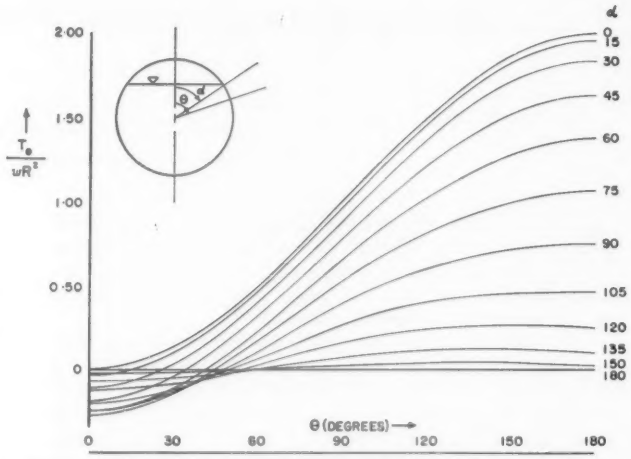


FIGURE 3. Direct force around the frame for various depths of fluid.

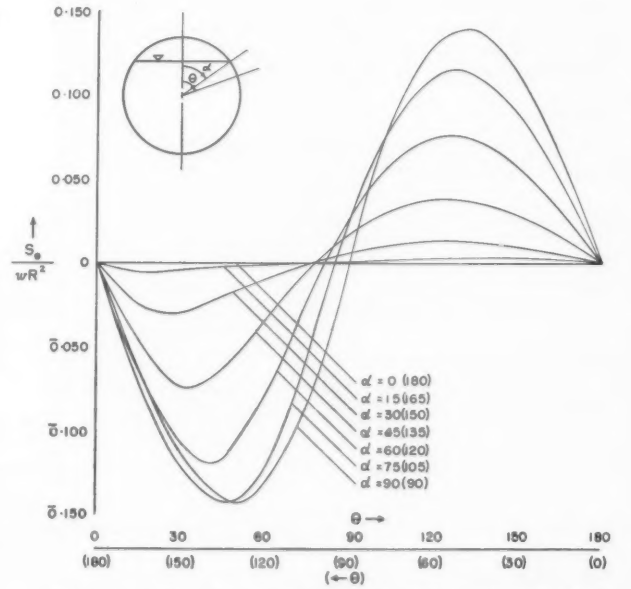


FIGURE 4. Shear force around the frame for various depths of fluid.

DISCUSSION

The elastic centre method of solution has been used in order to avoid having to solve simultaneous equations involving very long coefficients.

Expressions (14) to (19) for bending moment, direct and shear forces in the frame require long and tedious calculation for any particular depth of fluid. For this reason a digital computer was used to evaluate these expressions for a number of different depths of fluid. The results are shown in graphical form in Figs. 2, 3 and 4, and any other cases may be interpolated from them.

When the cylinder is full the solution corresponds to the pure membrane state discussed, for example, in Timoshenko's *Theory of Plates and Shells*, p. 384. The simplicity of this solution, with only varying tension in the frame, immediately prompts the question, is there some depth of fluid which gives a greater, or more critical, stress in the frame by a combination of bending moment and direct force?

The maximum bending moment in the frame is seen to occur when the cylinder is half full, and its position to be at the level of the fluid surface. Also the maximum bending moment that occurs at each point in the frame is brought about, for a large part of the frame, by the cylinder being half full of fluid. A point not immediately obvious from the general expressions, is that there is a type of symmetry present in the distribution of bending moment and shear force. Thus the bending moment (shear force) at position θ with the fluid at depth α, is equal to the bending moment (shear force) at position $(180-\theta)$, with the fluid at depth $(180-\alpha)$.

Flexibility of the frame may well result in the reacting shear flow distribution not being sinusoidal. The modifications to the stress distribution in the frame because of this would be such as to reduce the peak stresses in the frame. For this reason the curves given will be useful for predicting peak bending moments and stresses in the frame at an early stage in the design. It is also felt that they fill a gap in the standard cases presented in the R.Ae.S. Data Sheets 03.06.01—03.06.03.

ACKNOWLEDGMENTS

Thanks are due to the staff of the Numerical Analysis Department for their help in the computing work, which was done by the Liverpool University's electronic digital computer. The author is also grateful to Professor J. B. B. Owen for his advice and encouragement during the preparation of the note.

Buckling of Unstiffened Shear Webs with Flanged Lightening Holes

by

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ALTHOUGH MANY investigators have set out to find a method of determining the buckling and failing stresses for unstiffened shear webs with flanged or unflanged lightening holes, it seems that so far no really satisfactory method has been found.

A number of empirical and semi-empirical expressions have appeared over the years which agree closely with the limited series of tests on which they are based, but which the writer has found not to agree with the general mass of experimental data which is now available on this subject.

Following a recent examination of the available data another attempt has been made to derive some expressions or formulae that would help the designer to estimate buckling and failing stresses of such panels, and as a first step a semi-empirical formula has been derived that appears to fit the test results reasonably well for the initial buckling case. It applies to panels with edges fixed.

NOTATION

a	depth of web without holes (in.)
A	hole spacing (in.)
b	width of web without holes (in.)
D	outside diameter of holes (in.)
E	Young's modulus (lb./in.²)
h	depth of web (in.)
m	indice
q_b	buckling stress (lb./in.²)

DERIVATION OF FORMULAE

For a plate without holes, from R.Ae.S. Structures Data Sheet 02.03.01, assuming all edges fixed:—

for $0 < b/a \leqslant 1{\cdot}0$, $\dfrac{q_b}{E}\left(\dfrac{b}{t}\right)^2 \simeq 8{\cdot}1 + 5{\cdot}3\left(\dfrac{b}{a}\right)^2$. (1)

for $0 < a/b \leqslant 1{\cdot}0$, $\dfrac{q_b}{E}\left(\dfrac{b}{t}\right)^2 \simeq 8{\cdot}1\left(\dfrac{b}{a}\right)^2 + 5{\cdot}3$. . (1a)

For a plate with holes (*see* Fig. 1),

when $D/h = 0$ then $b/a = 0$

and when $D/h = 1{\cdot}0$, then $b/a \simeq h/(A-D)$

from which it is assumed that $\dfrac{b}{a} = \dfrac{h}{(A-D)}\left(\dfrac{D}{h}\right)^m$ . . (2)

The buckling stress for a plate with holes and edges fixed might be

$$\frac{q_b}{E}\left(\frac{b}{t}\right)^2 = \left(1-\frac{D}{A}\right)\left\{8{\cdot}1 + 5{\cdot}3\left(\frac{b}{a}\right)^2\right\} \quad \text{for } 0 < b/a \leqslant 1{\cdot}0 \qquad (3)$$

or

$$\frac{q_b}{E}\left(\frac{b}{t}\right)^2 = \left(1-\frac{D}{A}\right)\left\{8{\cdot}1\left(\frac{b}{a}\right)^2 + 5{\cdot}3\right\} \quad \text{for } 0 < a/b \leqslant 1{\cdot}0 \qquad (3a)$$

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and substitution for b/a from (2) leads to the equations

$$\frac{q_b}{E}\left(\frac{h}{t}\right)^2 = \left(1-\frac{D}{A}\right)\left\{8{\cdot}1 + \frac{5{\cdot}3\left(\frac{D}{A}\frac{A}{h}\right)^{2m}}{\left(\frac{A}{h}\right)^2\left(1-\frac{D}{A}\right)^2}\right\} \quad . \qquad (4)$$

$$\frac{q_b}{E}\left(\frac{h}{t}\right)^2 = \left(1-\frac{D}{A}\right)\left\{\frac{8{\cdot}1\left(\frac{D}{A}\frac{A}{h}\right)^{2m}}{\left(\frac{A}{h}\right)^2\left(1-\frac{D}{A}\right)^2} + 5{\cdot}3\right\} \quad . \qquad (4a)$$

Limiting values of parameters A/h and D/A that determine which equation to use, are found by putting $b/a = 1{\cdot}0$,

i.e. $$\frac{b}{a} = \frac{1}{\frac{A}{h}\left(1-\frac{D}{A}\right)}\left(\frac{D}{A}\frac{A}{h}\right)^m = 1{\cdot}0.$$

Taking the value of m to be 0·5, curves of $(q_b/E)\,(h/t)^2$ against A/h for various values of D/A were plotted from these formulae and compared with experimental results from Refs. 1, 2, 3 and 4. These results showed considerable scatter, but even allowing for this the agreement with the curves was not good.

The test results were examined in an effort to determine the factors responsible for the scatter, but because of the number of parameters involved it was not possible to obtain any conclusive results. It was found however that the form of the flange did not seem to be a significant variable within the range of configurations normally used.

To reduce the scatter somewhat, the experimental results were then plotted as $(q_b/E)\,(h/t)$ against A/h for various values of D/A and compared with curves from the following amended formulae:—

$$\frac{q_b}{E}\left(\frac{h}{t}\right) = C\,(1-D/A)^2\,(8{\cdot}1 + 5{\cdot}3a) \quad \text{for } 0 < b/a \leqslant 1{\cdot}0 \qquad (5)$$

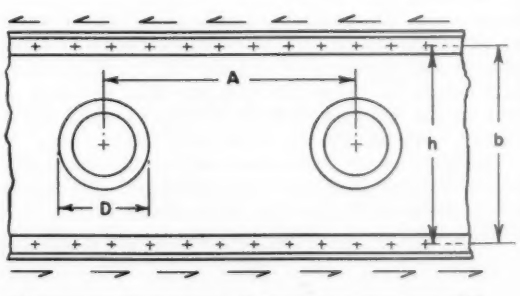

FIGURE 1.

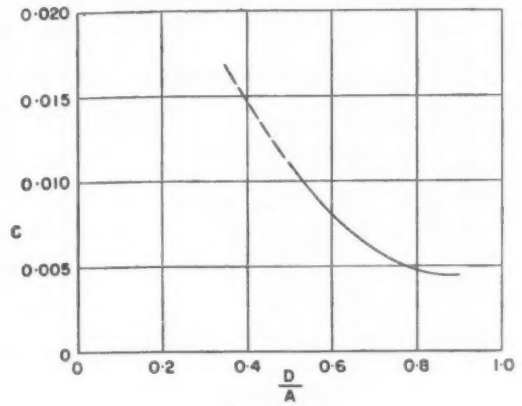

FIGURE 2.

$$\text{or } \frac{q_b}{E}\left(\frac{h}{t}\right) = C\,(1-D/A)^2\,(8{\cdot}1\alpha+5{\cdot}3) \quad \text{for} \quad 0 < a/b \leqslant 1{\cdot}0 \qquad (5a)$$

where $$\alpha = \frac{\left(\frac{D}{A}\,\frac{A}{h}\right)}{\left(\frac{A}{h}\right)^2\left(1-\frac{D}{A}\right)^2}$$

and C is a factor dependent on D/A.

Values of C were determined by finding the best fit curves through the experimental points for each value of D/A and Fig. 2 gives a plot of C against D/A.

The plot of $(q_b/E)\,(h/t)$ against A/h for various values of D/A is given in Fig. 3.

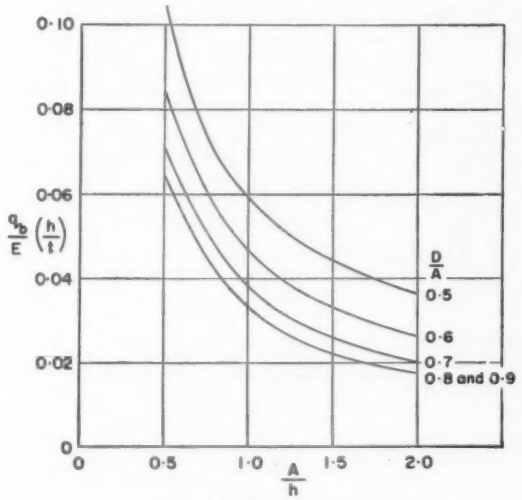

FIGURE 3.

CONCLUSION

Although the curves derived from formulae (5) and (5*a*) fit the available experimental results reasonably well, it is felt that a comprehensive programme of tests should be carried out. For, although there is a considerable body of data already available, most of it relates to rather limited ranges of what now appear to be the significant parameters of the problem.

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Probing Interplanetary Space

by

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THE PROBLEM of launching rockets to explore conditions in interplanetary space formed the subject matter of a previous note by the author[1]. In this note further aspects of such exploration by probes are considered.

The orbits considered in the previous note were elliptic, and touched the orbit of the Earth at the conclusion of each journey around the Sun. For journeys within the Earth's orbit it is of interest to consider the situation in which the probe first enters one of these elliptic orbits and then, at the point of closest approach to the Sun, is placed in a circular orbit around the Sun.

Unlike its planets, the Sun is not a solid body. Its observable "surface" exhibits pronounced changes. The surface features rotate at different rates, the period of rotation at the equator being just under 25 days, and progressively greater as the latitude increases, as shown in Fig. 1. The solar equator is inclined to the ecliptic, the plane of the Earth's orbit around the Sun, at an angle of just over 7°, so the movement of a surface feature as seen from the Earth does not generally follow a straight line, but one that is slightly curved.

At present it is only possible to observe conditions on the Sun on the hemisphere visible from the Earth at a given time. Many phenomena occur in cycles, so that the probable nature and extent of disturbances on the side not visible may be predicted, as may those about to appear on the visible side. It would be of advantage to have a complete picture of the behaviour of the solar surface from direct observation.

One solution to this problem would be to establish solar observation satellites. A typical category is suggested by

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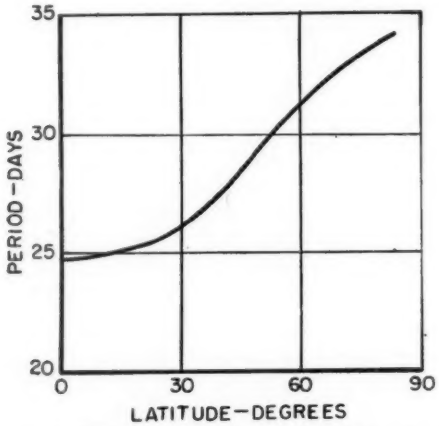

FIGURE 1. Rotational period of Sun's surface at different latitudes. (Data from Ref. 2.)

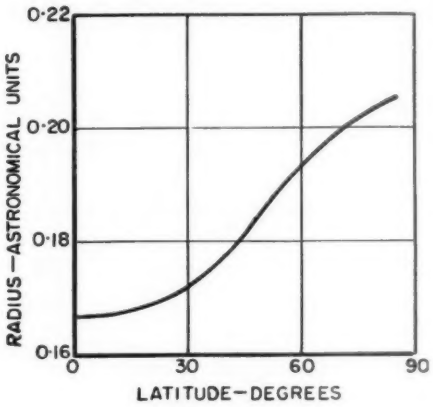

FIGURE 2. Radius of orbit of solar observation satellite permitting stationary observation of different latitudes.

the rotational periods of the surface levels. A satellite placed into a near-circular orbit of 25 days duration, for example, would be able to observe an apparently stationary surface in equatorial regions if the orbit were positioned in or close to the equatorial plane. The 25 day zone on the surface corresponds to that for the most intense sunspot activity. A series of such satellites spaced apart by equal angular distances would permit the greater part of the surface to be continuously observed. The situation would be similar to that proposed for Earth satellites in circular orbits above the equator of 24 hours duration for terrestial observation and communication purposes.

Stationary observation of a higher latitude calls for a longer period of rotation in orbit. The dependence of the radius of the orbit on the observed latitude is shown in Fig. 2. The orbit must still lie in the equatorial plane of the Sun, whatever the latitude observed, and so the value of stationary observation of the higher latitudes is not great.

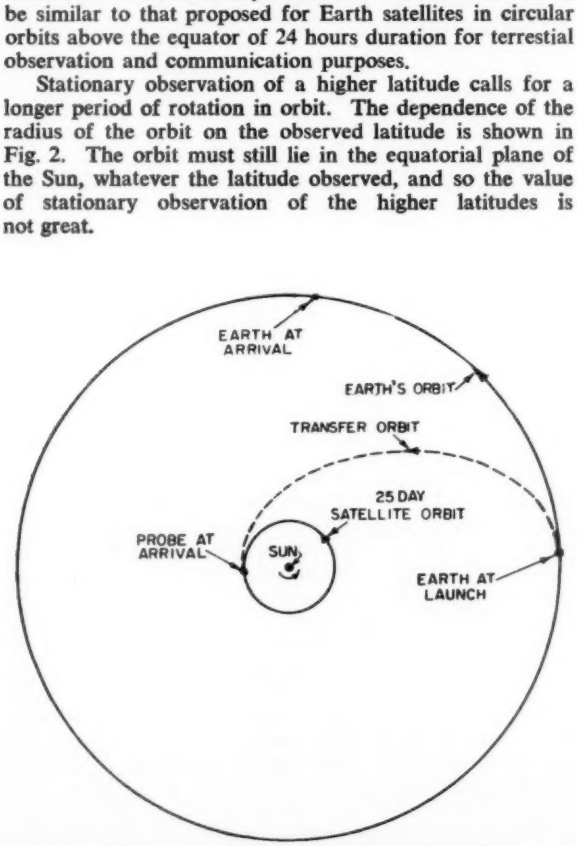

FIGURE 3. Transfer orbit for solar observation satellite.

The distances of orbits given in Fig. 2 are all within the orbit of the nearest planet to the Sun, Mercury. The closest of those under consideration, the 25 day orbit, could well constitute a goal for the solar explorers of the next few decades. That it is a difficult one to attain will now be indicated.

The intensity of the solar energy radiated across space is spread by the inverse square relationship, and in the vicinity of the Earth's orbit it is about $\frac{1}{4}$ Kw./ft.^{2} In the vicinity of the 25 day orbit it would be increased to $4\frac{1}{2}$ Kw./ft.^{2} Admittedly the satellite radiates heat to surroundings at effectively zero temperature conditions, but the problem of keeping it and its instruments at a suitable temperature would be a considerable one. If a highly reflective surface is to be used on the sunlit side, the problem would be one of maintaining the properties of that surface in the presence of bombardment by radiation and by meteoric dust.

The vehicle performance requirements to place the satellite in orbit are high. The satellite would first be launched on an elliptic path from the Earth, as shown in Fig. 3. The path would touch the Earth's orbit at launch, and the circular orbit around the Sun on arrival. The inclination of the solar equator to the ecliptic will call for a slightly higher performance than the figure to be quoted here, but in this simple analysis the inclination has been ignored. The 25 day circular orbit is at a distance from the Sun of just under 0·17 astronomical units, and the velocity to be attained by the rocket in order to enter the transfer semi-ellipse is 11·0 miles/sec. On arrival at the 25 day orbit, a retarding manoeuvre is carried out. The velocity change involved here is 13·8 miles/sec., a larger quantity than that required on departure from the Earth.

The total requirement of 24·8 miles/sec. is beyond possibility of attainment in the present state of technology. It is in excess of the figure of 19·8 miles/sec. required for a direct fall to the Sun.

It will be seen from Fig. 3 that the duration of the transfer orbit is such that the Earth moves through about 80° during this part of the flight. This will assist tracking and control of the vehicle, in that interference effects caused by the Sun will be less than if the probe at arrival was to lie closer to a line joining Earth and Sun. Nevertheless, solar interference effects will have to be allowed for, and indeed will be a constant problem when data is transmitted between the satellite and the Earth.

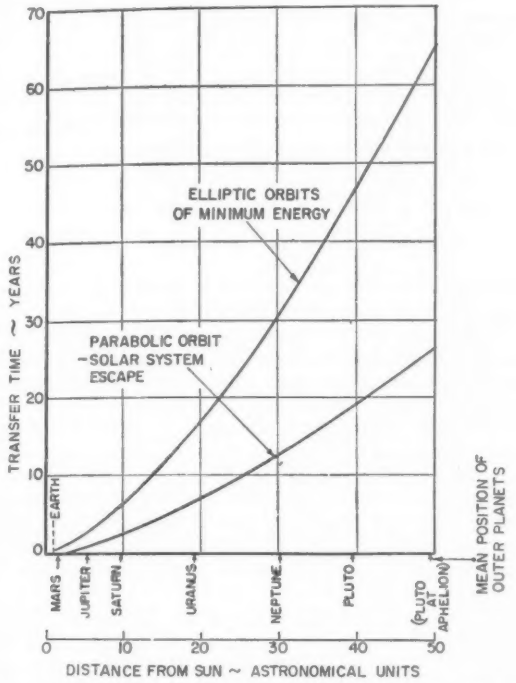

FIGURE 4. Transfer times for journeys to the outer planets.

It has been seen that journeys within the Earth's orbit involve high performance requirements. It was demonstrated in Ref. 1 that journeys outside the Earth's orbit are much easier in this respect. To voyage completely beyond the limits of the Solar System, a velocity of 10·3 miles/sec. is required. However, such journeys are subject to serious limitations on the time involved in travelling over great distances.

The problem is illustrated in Fig. 4. The time taken to travel from the Earth to different distances from the Sun is shown for two cases. The upper curve is for travel along a semi-ellipse that touches at each end the orbits of the planets concerned. This is the easiest path from the velocity requirement viewpoint, but the transfer times are disagreeably high for the more distant planets. A flight that did not stop at the destination, but involved travelling past it and returning on the second half of the ellipse, would take twice the time given. A traveller could spend all his adult life on the voyage.

The journey time may be reduced by travelling faster, and this, of course, increases the demand on vehicle performance. As an example of the way times may be reduced, the lower curve of Fig. 4 is plotted for departure from the Earth at a velocity of 10·3 miles/sec. The transfer

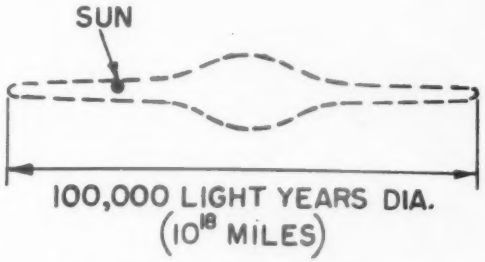

FIGURE 5. Cross section of the Galaxy.

times are less than half those for the minimum energy orbits, though still appreciable for distant flights. Difficulties arise not only from the higher required initial performance, but also in the increased requirements at the destination planet resulting from the inclination of the vehicle's path, a parabola, to that of the planet, an ellipse, if contact is to be effected. If the planet is passed, but a return to Earth is desired along a similar orbit, the escape path must be left by carrying out a velocity change to permit the vehicle to fall back towards the Sun and towards the Earth.

At its greatest distance from the Sun, the outermost known planet, Pluto, reaches a distance of about 50 times the Earth's distance from the Sun, or 50 astronomical units. The problems of exploring conditions within that boundary are immense, and man is faced with such a variety of possible projects that it is difficult to believe that he will ever wish to take the opportunity of striking farther afield. Yet, in the long run, such a view must seem parochial. The Sun is just one star in the great cloud of stars that make up our Galaxy. This cloud is roughly circular in shape, and seen edge-on looks rather like Fig. 5 in outline. The Sun is about two-thirds of the way out from the centre, and from a distance is doubtless undistinguished.

The Galaxy rotates, and exerts a gravitational attraction on its individual components. To escape from it, having escaped from the Sun's field, a vehicle would have to reach a velocity of about 50 miles/sec. relative to the Sun. This would confer upon it a velocity of about 200 miles/sec. relative to the centre of the Galaxy. At such a velocity it would take tens of thousands of years to reach the nearest stars and about 10^8 years to reach the edge, and so effect escape.

Our Galaxy is only one among hundreds of millions. Will there ever be a time in man's history when the demand for high performance flying machines will disappear?

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(Correspondence on this note is invited.—Ed.)

Following on Coventry and Yeovil, an early Branch was BRISTOL, to be closely connected with the Bristol Aeroplane Company (and its later and local subsidiaries) and with the University of Bristol.

"An inaugural Meeting was held at the Engineering School of Bristol University on Friday 25th April 1929. Captain J. L. Pritchard, Hon.F.R.Ae.S., Secretary of the Royal Aeronautical Society, attended the Meeting.

"It was decided that a Bristol Branch could, and should, be formed and Office bearers were provisionally elected as follows:—Chairman: Professor A. J. Sutton Pippard, Vice-chairman: Mr. A. H. R. Fedden, Hon. Secretary: Mr. C. W. Tinson, Hon. Treasurer: Mr. A. V. Piper, and Committee: Captain F. S. Barnwell, Mr. H. Bolas, Mr. H. J. Pollard, Mr. Berry."

So reads the first official record of the Bristol Branch, and 31 years later and at a time of change in the Industry and at Bristol, there is a sense of historic continuity and almost of coincidence in reading this document.

Another Bristol University Professor is today President —A. R. Collar—and a senior Engineer is Chairman—Mr. H. Giddings. Captain Frank Barnwell, killed in 1938, is remembered in the now famous Memorial Lecture bearing his name. The Seventh such lecture was recently given by Sir Roy Fedden and in the large and distinguished audience were Captain Pritchard and Mr. Tinson, and no less than four Past-Presidents and ten Past-Chairmen, going back to 1931.

1960 was the Fiftieth Anniversary of the Bristol Aeroplane Company, so both the Company and the Society were very aware of historic and earlier years.

The first ten years of the Branch were a time of steady growth and influence, to come to an abrupt halt in 1939; but although activities ceased, a working Committee remained in Office to preserve the identity of the Branch. A beginning was made again in 1943 and by 1944 activity was normal, although with only 70 members. By 1948 this had reached over 300, and after a peak of nearly 700 the figure is today about 600, the second largest in the Society and with the highest proportion of Main Society Members.

1954 was the 25th Anniversary of the Branch, and the occasion was marked by the inauguration of the First Barnwell Memorial Lecture. This was given by Major G. P. Bulman, who was also in the audience for the Seventh. Also present on this recent occasion was Mr. Cyril Uwins, a Past-President of the Branch, who gave the previous Memorial Lecture on "Bristol Prototypes," and so was completed a trilogy of Barnwell the man, his aeroplanes and now Fedden's engines, which powered most of them.

Professor Collar had himself given a Memorial Lecture, and another present to have done so was Sir Alfred Pugsley, a previous Chairman. A Barnwell Memorial prize was generously endowed by the Bristol Aeroplane Company, who over the years have given much encouragement and great help to the Branch.

Continuity is also evident in Mr. R. N. Westaway, a founder Member, Treasurer for 21 years, Past-Chairman and *still* on the Committee. Defiantly a Branch Member, he has declined to join the Main Society.

The long list of Lecturers over 31 years would cover most of the great names of British, and some of international, aviation; within one year of recent date the Branch was honoured that two lecturers flew the Atlantic, and one flew from Israel, to lecture to Bristol. At a junior, but important, level the Branch was pleased that the first two winners of the N. E. Rowe Medal Competition were Bristol entrants.

Fifteen meetings were held in the Lecture Session just finished and such has been the pattern of this busy Branch, which also organised the first Branches Conference away from London. Possibly unique to Bristol are the annual Section Lectures, when three lectures on a specific subject are given in three weeks (once four in four); these have been most successful and of a high technical content. The last three subjects have been on the "Modern Civil Air Liner," "Guided Weapons" and "Outer Space"—and to progress from here is possibly more religious than technical and presents the new Committee with quite a problem. Bristol will have to cease to be out of this world.

The Branch is proud of its close connections with the Society in London, and from Bristol have come Presidents, a Treasurer, Members of Council and of Committees; serving at this time are the President, a Member of Council, and Members of the Finance, Awards and Branches Committee.

The President now leaves Bristol and, in recalling his previous memorable year as Bristol President, the Branch have asked that they here record their appreciation, with good wishes for the future. Peter Masefield has lived aviation even to being his own pilot and Frank Barnwell, also a pilot and three times Chairman, would have approved of the Chipmunk (if not of its wing loading) and have appreciated such service to the Branch and to the Society. —G.W.-W.

Branch News

BROUGH has just held its Annual General Meeting (on 13th April) and reports an increase in membership during the year to 695—which earned a well-deserved tribute from Mr. Laight, the Chairman, to the Branch Officers and "the grapevine"—those "keen behind-the-scenes workers" as Blackburns "The Courier" describes them. Mr. N. E. Rowe continues as Branch President for another year and Mr. B. P. Laight, Mr. S. Wrightson and Mr. A. D. Howarth continue as Chairman, Hon. Treasurer and Hon. Secretary respectively.

Graduates' and Students' Section

Visit to Ford Motor Company Ltd., Dagenham

The Ford Works at Dagenham were visited on Wednesday 24th February 1960 by a party of some twenty members who spent an enthralling afternoon seeing the whole scale of motor production from raw materials to finished products. Only by seeing this factory in operation can one realise how it is possible to produce 1,900 vehicles a day, of which 600 are Ford Anglias.

Our guide first took us to the rolling mill, where we saw white hot billets of steel being steered backwards and forwards between the grooves of the rollers, by operators using long pairs of tongs, until the bar had been reduced to the required size and shape.

We next passed alongside the precision machining line which is some 200 yards in length and almost fully automatic, requiring only the minimum of manual work. The forgings and castings could be seen taking shape as the various operations followed each other in a regular sequence. The operations were controlled by means of signalling lights and push buttons.

The next department visited was the tractor production. Here we saw a continuously moving line of components gradually being assembled into a complete tractor, which is filled with petrol, started with the first turn of the handle and then driven off to make room for the next one.

We had quick glimpses of the constant temperature Standards Room of the Quality Control Department, where a check is kept on the accuracy of the testing equipment used throughout the factory and where measurements can be made to two-millionths of an inch; of the Chemical and Metallurgical Laboratories, where regular tests are made on all materials used to ensure that the highest standards possible are maintained, and the Medical Department, where a staff of over fifty including four medical officers, maintains the high standards of employment conditions.

Unfortunately the shortness of the visit prevented us from seeing in any detail the foundries, the coke ovens, the blast furnace or the power station. In the foundries some 4,000 men produce more than 72,000 castings a day. Dagenham is the only motor factory in Europe which makes its own coke, coke oven gas and by-products and also the only one in Great Britain which makes its own pig-iron. The Ford blast furnace has consistently broken records in the amount of iron produced for its size and has only been shut down twice, for relining, in 26 years. The power station, if required, could supply the domestic needs of a city of more than 350,000 people.

Courtesy of Ford Motor Co. Ltd.

Ford Anglia Assembly line at Dagenham.

The final section of the factory we visited was the Body Manufacturing Group and the Paint, Trim and Assembly Building. These buildings are located next to each other and connected by a 725 ft. enclosed body conveyor bridge.

In the huge press shops we saw the steel roofs, door panels, bonnets, etc. being made, along with all the other hundreds of pressed steel components required for body construction. We then passed through the assembly shops, where we saw the components being welded together and gradually taking on the familiar shape of motor bodies. At this stage the bodies are ready for their journey over the enclosed bridge to the Paint, Trim and Assembly Building. Here they are automatically fed into either one of two identical paint systems. They are given a phosphate surface coating and then an under-body dip with a special primer paint to give resistance to corrosion. In the primer spray booth, bodies receive one red and one grey coat of paint and are then dried in ovens before having two coats of enamel applied in a 120 ft. spray booth. The bodies can be sprayed in any one of twelve colours. After drying, the bodies move on to the Trim operations, which include assembly of door handles, windows, pedals, etc. The bodies are then transferred to a high level conveyor so that underside assemblies, such as fuel tank, brake pipes, etc. can be fitted while steering gear, radiator, etc. are fitted from the topside. The final stage of assembly now arrives when the bodies are lowered on to the engines and their associated components to complete the assembly. The completed motors are then driven on to "toe-in" and "roll-test" machines to test steering, brakes, engine, etc. Finally, after a sales acceptance inspection, the vehicles are ready to leave for despatch.

Throughout the visit we were greatly impressed by the smooth organisation of the factory which keeps the production line moving the whole time.

Unfortunately it is difficult in such a short article to do adequate justice to such an interesting and informative visit. Much of the credit for this was due to our expert guides whom we gratefully thank.—N.R.C.

Summer Dance and Cricket Match

For what is believed to be the first time in the history of the Graduates' and Students' Section, the Committee has challenged the rest of the Section members to pick a team to show their prowess on the Cricket field.

As most members know, the building of the new Lecture Hall at 4 Hamilton Place precludes our holding the usual Summer Party and it is hoped that this informal and, we hope, light-hearted match—which will be followed by a dance—will help to fill the void. There is also a slightly more serious purpose behind it, *i.e.* to discover suitable talent to enable the Section to take on one of the Engineering Institution's Graduates' and Students' Sections, if they accept.

Bearing this in mind the Committee hopes that any cricketers in the Section who would like to participate in an evening's entertainment, as well as the possible representative match later, will get in touch as soon as possible with the organiser, A. H. FRASER-MITCHELL, 59 CAMBRIDGE ROAD, KINGSTON-ON-THAMES, SURREY—or telephone, during office hours, GLADSTONE 8000, Extn. 29. (*Note*:—Those who have already written to Mr. Moulton need not write again —*Hon. Ed.*)

The Committee's challenge match will be on Friday 24th June at the Handley Page Sports Club ground at Cool Oak Lane, Hendon.

The ground is pleasantly situated on the banks of the Welsh Harp and is easily reached.

With the co-operation of the Handley Page Sports Club the Pavilion and Bar will be available throughout the evening and after stumps are drawn there will be dancing to recorded music and other entertainment. There will be no charge for this and the Committee hope that many spectators will come along to see the match and stay afterwards.

As regards players, we hope that as many as possible will send in their names—we will try to give you all a game. It really does not matter what standard you are—the Committee team is probably better at tiddleywinks than with a bat or ball! Neither do you have to provide your own equipment, other than a pair of suitable shoes or plimsoles—bats, pads, etc. have very kindly been loaned to us by the Sports Clubs.

So note the date and give us your support.—A.H.F.M.

THE LIBRARY

Reviews

SATELLITES AND SCIENTIFIC RESEARCH. *Desmond King-Hele. Routledge and Kegan Paul, London, 1960. 180 pp. Illustrated. 21s.*

This book presents an account of the general characteristics of satellites and their uses for scientific research. The first main Section is devoted to a description of the life history of a typical earth satellite, from launch, through slowly varying orbital motion under the influence of the earth's gravitational field and atmospheric drag, to the final rapid and often spectacular plunge into the lower layers of the atmosphere. The optimum launching procedures for near earth orbits are clearly explained with simple numerical examples, including the effects of staging; of rather more interest is the treatment of the orbital perturbations caused by the gravitational effect of the earth's equatorial bulge and the estimation of satellite lifetime in relation to orbital eccentricity. Useful formulae are given to allow both lifetime and variation of orbital period to be calculated once initial values of eccentricity and daily change in period of revolution are known. The monotony of reading yet again the particulars of all the satellites launched from 5th October, 1957 until the end of 1959 is relieved in Chapter II by a handy chart of lifetimes, actual and estimated. The chapter on tracking describes the various optical and radio methods available and quotes the accuracy obtainable from each.

A subject to which the author has made notable personal contributions is the calculation of the exact figure of the earth from accurate orbital measurements of appropriate satellites. The methods and results are well presented and the correction to the previously accepted value for the flattening at the poles is rightly hailed as one of the earliest fruits of orbital analysis. Succeeding chapters cover the measurement of air density and the discovery of periodic variations in density at heights between 100 and 500 miles. The process of elimination which leads to the conclusion that the density variation must be due to the influence of some form of solar activity with its well-known 27-28 day periodicity is unfolded with fascinating clarity. Well might this chapter, rather than that on the Pattern of Research, be prefixed by the author's quotation from Pope's Essay on Man :—

" Go, wondrous creature! mount where Science guides,
Go, measure earth, weigh air, and state the tides."

Later chapters describe the Van Allen radiation belts, the sun's radiation, meteorites and some limited aspects of manned space travel. Despite the dramatic title " Beyond Earth's Grasp," the last chapter is short and rather subdued. The end comes abruptly, perhaps like the final stage in satellite life, and leaves no real message.

Throughout the book the author's powers of elegant and clear explanation of basic principles, illustrated by well-chosen examples, make the text both instructive and a real pleasure to read. The diagrams are well produced; all references are lised at the end of the book together with a short index. There are at times signs of indecision between a treatment suitable for the specialist and that for the general reader. Little is said about design of satellites or launching vehicles, and instrumentation is completely neglected. Like Jeffreys' *Mathematical Physics*, every chapter has an apt poetical prefix, a sign both of King-Hele's belief in combining scientific writing with good literary style, and of the astounding versatility which allowed him to publish within a few months this book on satellites and a well-received, new interpretation of Shelley (His Thought and Work).—W. H. STEPHENS.

THE NEW FRONTIER. *Man's Survival in the Sky. K. G. Williams. William Heinemann, London, 1959. 161 pp. Illustrated. 21s.*

As the title suggests, this book is intended for " anyone, young or old, who is interested " in the physiological and psychological problems of flight at high speeds and altitudes, including space-flight. Observing signs of a scientific conscience in the author, and being myself not young, not inescapably old, and not a layman, I obtained a boy of the science sixth-form variety and suitable interests for my *experimentum in corpore vili*. He writes : ". . . a very wide coverage . . . all the material for a good and informative book, but there is little sign of an attempt at logical and coherent order . . . much useful information omitted . . . The general impression conveyed is that the author, in keeping his writing very simple, has lost interest in it himself . . . and it becomes boring. . . ." A harsh verdict; but my " general reader " felt himself put upon by the statement that primary cosmic rays are particles travelling at " unimaginable " speeds. An even more woolly remark, only a few lines farther on, triggered the explosive comment: " What the blazes is *universal matter*?" What indeed?

The truth, I believe, is that, judged against the proper background, Dr. Williams has achieved a very creditable level of accuracy, comprehensiveness, logical order and simplicity. Admittedly it was naughty of one so well-informed to say that the sense organs in the semicircular canals of the inner ear are probably stimulated by " pressure changes in the endolymph and not actual flow of fluid " (which is wrong); and, later, that disorientation is due to " the fact that the fluid . . . tries to keep on moving after an angular acceleration has stopped " (which is misleading). But some standard physiological textbooks are almost equally muddled and contradictory, although the mechanics of the semicircular canals has been well understood for over ten years.—W. E. HICK.

THEORETICAL ELASTICITY. *Carl E. Pearson. Harvard University Press, 1959. 218 pp. 48s.*

The title of this work can be given full marks for conciseness and accuracy. The same can be said of the book itself and herein lies both its strength and weakness. It makes no claim to the completeness of a teaching textbook, but is content to be a thorough account of the mathematical theory of elasticity and its main developments, disdaining the use of examples except in the first two chapters. These cover painstakingly the mathematical preliminaries, including all that is required of vector and tensor analysis, and nearly one quarter of the book is devoted to them.

The chapter on stress which follows gives a succinct and economical definition of stress as a tensor, and one

might say that this economy is characteristic of the author's style of writing—its clarity carries the reader along from step to step so rapidly that he is liable to be deceived by the apparent simplicity of the subject. That the difficulties are still there occurs to him when he tries to apply these apparently simple concepts! The chapter on deformation works from both the Lagrangian and Eulerian points of view and derives the compatibility equations in most elegant fashion. The economy of tensor notation is shown again in the following chapter where the equations of linear elasticity in a homogeneous material are rapidly derived.

One feels that here is demonstrated both the strength and the weakness of the tensor treatment of elasticity. On page 89 the author says that "there are few fields in which the interplay of physical reasoning and mathematical analysis is as important as in elasticity." The tensor notation as it were allows the basic equations almost to derive themselves, and so the discipline of physical reasoning is in fact rather suppressed in the early stages where it ought to be under training.

A chapter on General Solutions describes all the standard solutions to the fundamental boundary-value problems, and is followed by others on Variational Methods, Thermoelasticity, Time Dependent Problems and Non-linear Elasticity.

The whole work is contained in a small compass and, as noted before, reads excellently. The difficulty for a reviewer is to define its range of usefulness. In his brief preface the author says that the book grew out of lectures given to graduate students and that "its purpose is to discuss modern methods of elasticity in a form which does not require extensive mathematical experience, and to provide a compact and convenient summary of such methods." The book certainly succeeds in its second aim, but one feels that the reader with limited mathematical experience, while appreciating its clarity, will find himself hard put to it to survive past Chapter V. However, it recommends itself as an excellent book for the stressman who has a working knowledge of his basic subject, and who can supply from his experience plenty of the absent examples, but who wants to master the precision of the underlying theory.—K. H. GRIFFIN.

THE CROWDED SKY. *Edited by Neville Duke and Edward Lanchbery. Cassell, London, 1959. 421 pp. 30s.*

There have been many anthologies about flying, but this is one of the most successful to date. It includes a most comprehensive and well-selected collection of extracts and is sufficiently ambitious in scale (421 pages) for the editors to have been able to spread themselves and achieve a reasonable balance in their choice of subject matter. Too often in the past such books have been disappointing because their publishers or authors have tried to compress too much material into too small a container. Like the majority of previous aeronautical anthologies, this book sets out to cover the complete span of the story of human flight in a series of passages from some of the more notable writings on the subject, but it does so in a restrained manner without spreading its net too widely. The book is divided—perhaps with some want of originality—into five parts: "Quest," "Mastery of the Air," "Wings of War," "Wings of Peace" and "Test Flying."

The first part covers that period of theorising and experimentation which preceded the conquest of the air. Particularly notable is a remarkable account from *The World* of June 7 1896—which this reviewer has not come across before—of an American boy on the end of a parachute who was sucked up off the ground by a whirlwind. This section ends with Major B. F. S. Baden-Powell's far-sighted summing-up, in his presidential address to the Royal Aeronautical Society in January 1903 (on the eve of the attainment of powered, sustained and controlled flight) of the military implications of the aeroplane, as he saw them in the light of his then recent experience in the Boer War.

The "Mastery of the Air" includes extracts dealing with ballooning, airships and aeroplane flying before the First World War. The latter, in particular, strike a nice balance between recalling the pioneering atmosphere at some of the first aerodromes, record flights, flying meetings, air races and the beginnings of military aviation. Particularly enjoyable—although it also appeared recently in *Flying Tales from Blackwood*—is the most amusing account by John Mackworth of his arrival in Farnborough in the early days of the R.F.C. "Wings of War" next plunges us straight into "The Falcons of France," "Double-Decker C.666," "Flying Fury," "Sagittarius Rising," and "War Birds"—all familiar titles to those who grew up between the Wars and acquired an interest in aviation from reading some of the many war flying books which were published—in particular by John Hamilton—during the latter part of that period. War flying between the Wars is effectively represented by extracts from a diary kept during the Spanish Civil War by Oloff de Wet, which originally appeared in Blackwood's Magazine and later formed part of *Cardboard Crucifix*. The Second World War is represented by selections from, among others, Paul Richey's *Fighter Pilot*, Terence Horsley's *Find, Fix and Strike*, Constance Babington-Smith's *Evidence in Camera*, Guy Gibson's *Enemy Coast Ahead* and Pierre Clostermann's *Flames in the Sky*. The enemy's point of view is given by Henn's *The Last Battle* and Knocke's *I Flew for the Führer*. The Korean War, with two selections, concludes this part of the book.

"Wings of Peace" first sets out to capture something of the atmosphere and fascination of flight. It succeeds without effort with familiar passages from T. H. White, Saint-Exupery and David Garnett, but it might have been even better if we could have had, let us say, Francis Chichester, Sir Gordon Taylor and John Leeming as well. The next section concentrates on record flights in the years between the Wars and finally there is one on gliding in which this reviewer was particularly pleased to see a short piece from Robert Kronfeld's *Gliding and Soaring*—a book which he has always thought gives a more honest picture of its subject than several others which have won greater acclaim.

The last part of *The Crowded Sky* is on "Test Flying" and—as is perhaps not surprising with Neville Duke as one of the editors—probably contains the best selection in the whole book. One's only criticism is that the period before the middle 1930s should have been covered more adequately: the writings of Wilfred Parke, Oliver Stewart and Norman Macmillan come immediately to mind.

On the whole, however, this is a satisfactory addition to anybody's library and one unreservedly recommended. So many of the better books on aviation are now out of print that it is only anthologies like this which can remind us of things worth remembering which might otherwise soon be forgotten.—PETER W. BROOKS.

AVAILABLE ENERGY AND THE SECOND LAW ANALYSIS. *E. A. Bruges. Butterworths, London. 124 pp. Diagrams. 25s.*

This useful little book deals with material that might perhaps occupy two or three chapters in a complete text-

book on engineering thermodynamics and, let it be said at once, in general the author handles his material well. The book appears to be one of a series of texts, each of which covers a limited field. Presumably publication in this form is determined by the sound philosophy that few major texts in this general field deal equally well with every topic and that it is better—and undoubtedly simpler—for a number of authors to write on their favourite topics. However, from the student's point of view, the price of a collection of such books chosen to suit his own particular requirements might prove prohibitive and it may well be that there is scope for a paper-backed edition.

From the technical aspect this is a worthwhile attempt to clarify a subject which is often misunderstood even by serious students of thermodynamics.

The first two chapters give a somewhat brief conventional introduction to the first and second laws of thermodynamics. Brevity may be justified, however, since copious references are given to more detailed texts. It is perhaps unfortunate that it might be implied from Chapter 2 that the Kelvin scale is the only absolute scale of temperature and that a misprint mars equation 2·28 at a vital point in the argument.

The concept of Available Energy and its application to the evaluation of irreversibility are well treated in the next two chapters which form the theoretical introduction to this method of thermodynamic analysis.

The second half of the book presents analyses of well-chosen examples which cover a wide range of interests.—H. BILLETT.

SIMILARITY AND DIMENSIONAL METHODS IN MECHANICS. *L. I. Sedov. Translated by Morris Friedman. Edited by Maurice Holt. Academic Press, New York, 1959. 361 pp. Illustrated. 5 gns.*

This is a translation of the fourth edition of a Russian book, the first edition having been published in Moscow in 1943. It is really two books under one cover. In the first three chapters, the basic principles of dimensional analysis are discussed and the theory is applied to the familiar problems of fluid flow.

The first chapter has the promising title "General dimensional theory," but the reviewer found it most disappointing. The book is said to be intended for "students who wish to learn dimensional analysis and similarity methods for the first time," but it is feared that the exposition given in the first chapter is far too short, and not clear in many points. In the discussion on units, the CGS and MKS systems are set out, but no mention is made of British or American systems based on the pound and the slug. If the astronomical system of measurement has to be mentioned at this early stage, it should be discussed in far more detail. The beginner is apt either to despair or to get wrong ideas when he reads that $M=L^3/T^{-2}$.

The space (a quarter of the first chapter) devoted to a general discussion on Newton's second law, could have been much better employed in detailing the units and dimensions of common physical quantities. The Π theorem is proved, in all its generality, but it is not referred to explicitly in the later chapters (although its results are used). The present reviewer feels strongly that, in any book on dimensional analysis intended for students, great clarity is needed in setting down the basic principles and methods. An air of mystery surrounds this simple subject.

A number of simple applications of dimensional analysis are given in Chapter 2. The discussion of heat transfer from a body in a fluid is strong meat for the reader, whereas, if the quantity of heat is expressed in mechanical units and a new fundamental dimension is assigned to temperature, even a beginner can follow.

The mathematical theory of viscous flow is discussed in detail in Chapter 3. The references given are mainly foreign, and mostly pre-war; no mention is made of the work of Batchelor and Görtler on turbulent flow.

The second half of the book is on unsteady gas flow (including the theory of spherical explosions) and astrophysical problems. The material here is mainly the work of L. I. Sedov himself and his research group in Moscow University from 1950 to 1957. The English translation of this part of the book is to be welcomed as it will lead to a closer acquaintance with recent Russian work in this field.—A. W. BABISTER.

INTRODUCTION TO THE THEORY OF COMPRESSIBLE FLOW. *Shih-I Pai. D. Van Nostrand, London, 1959. 385 pp. 73s. 6d.*

This book is based on lectures given by Professor Pai in an advanced aerodynamics course at the Department of Aeronautical Engineering of the University of Maryland. After an introductory chapter, there is a chapter describing the thermodynamic and physical properties of gases. This is followed by eleven chapters dealing with inviscid compressible flow for both steady and unsteady motion. These chapters include detailed descriptions of the theories of subsonic and supersonic flow and, also, useful introductions to the theories of transonic and hypersonic flow; a chapter on rotational flow is also included to cover such problems as supersonic flows with detached shock waves. The next two chapters discuss viscous effects and boundary layer theory, including the effects of chemical reactions. Finally there is a brief survey of magnetogasdynamic theory. A set of problems is included at the end of each chapter, together with a useful list of references.

According to the preface, the work is intended to give a theoretical introduction to the dynamics of a compressible fluid, including discussion of the basic assumptions, the formulation of the theory, and the various techniques that may be used to achieve solutions. On the whole, the author satisfies this objective admirably, and covers all of the theoretical ground that might be expected in an undergraduate course, as well as much that would be more appropriate to postgraduate studies.

Further reading of works dealing with experimental methods and results, and practical applications would, of course, be required for a balanced understanding of the subject.

The book is well reproduced, and the reviewer found that the material was clearly presented and described. He recommends the book to those requiring an introduction to the theory of compressible flow (especially the inviscid theory) which goes further than the average textbook without becoming involved in the detailed discussions of a specialised treatise on a particular topic.—D. W. HOLDER.

NEW ZEALANDERS WITH THE ROYAL AIR FORCE. Vol. III. *Wing Commander H. L. Thompson. War History Branch, New Zealand, 1959. 409 pp. Illustrated. No price quoted.*

This is the third, and final, volume of this part of the Official War History. Volume I, published in 1953, dealt with all the various activities in the air war in the European theatre from 1939 to 1942, and Volume II completed the

record of these operations. These volumes were reviewed in the May 1957 JOURNAL (p. 363).

Now in Volume III we leave the European scene and with this change of locus there is such a marked alteration in the nature, and surrounding circumstances, of the operations that it reads like the story of several different wars. Although the stories of the actual engagements are much the same throughout, it is in the operating conditions in which the crews had to fly, maintain the aircraft, and take their rest, if any, that these differences are so apparent.

For example, keeping any form of machinery working in the sand-laden atmosphere of the Western Desert must have been something of a nightmare; flying in the turbulent and treacherous air over Burma and Malaya must have had its moments, particularly when physical condition was lowered by the effects of the sticky heat on the ground. Malta, too, produced its own particularly concentrated concoction of ceaseless enemy activity, supplies which seldom arrived, a desperate food situation and on top of all that the imperative need of somehow ensuring that there were aircraft and crews ready to meet the next attack.

Although there were these differences in detail one thing remained constant and that was the spirit of determination with which the Royal Air Force prosecuted its various jobs of attack, defence, transport, air sea rescue, or even the routine and sometimes monotonous patrolling.

Wing Commander Thompson has now completed his saga of the many New Zealanders who served with the Royal Air Force. This was a contribution to the war effort in which all their fellow countrymen can take pride.

The author has patiently amassed a considerable collection of information on the exploits of some of those New Zealanders and the amount of work involved in producing these reference works would have daunted a lesser man.

Volume III like its predecessors is well illustrated and contains appendices giving details of the aircraft used by both sides, and a comprehensive index.—B. CORNTHWAITE.

A TEXTBOOK OF FLUID MECHANICS FOR ENGINEERING STUDENTS. *J. R. D. Francis. Arnold, London, 1960. 332 pp. Illustrated. 24s.*

The author states that his aim is to produce a simple textbook suitable for the first two years of the London B.Sc. (Engineering) degree course and the Higher National Certificate. In the preface he explains that most of the available textbooks and treatises on fluid mechanics are in general too complicated for the engineering undergraduate to master and that there is therefore a need for a new textbook in which the mathematical treatment is reduced to a minimum.

If for the moment we accept that this is true we might also add that the modern author writing on fluid mechanics must consider the rapid expansion of knowledge in this subject and the wide range and complexity of problems now being treated. It would also seem essential that at the undergraduate level of teaching the basic physical facts should be presented clearly and precisely. The methods of approach, not necessarily mathematical, should be developed in such a way that the student can appreciate the tools available and so apply his knowledge to a wider area of interest. Now it is well known that most engineering students learn best from working with examples on applications to the theories they are taught, and hence in an undergraduate's textbook practical applications should always be emphasised and in particular the backing up of theory with experiment. Nothing is more frustrating and tantalising to the engineering student to finish a theory and then find that the assumptions made do not lead to a practical application or do not give results in agreement with experiment. The selection of material for such a work on fluid mechanics is therefore not without difficulties, and places much emphasis on the ingenuity of the author. Moreover it would not seem desirable to omit sections because their usual treatment is often of great mathematical complexity, or at least as it would appear to the undergraduate. Perhaps in many cases a physical appraisal is the better approach thereby whetting the student's appetite for more. But nevertheless an elementary mathematical treatment is by far and away the most satisfactory and its foundation, when built on sound physical assumptions, is possibly the only satisfactory way the student can learn and go on to master more recent researches in his subject.

The subject matter selected by Mr. Francis ranges from the flow in pipes, rivers, canals, pumps and turbines to the flow of gases at high speeds, where the latter chapter has been written by Mr. G. Jackson. Few experimental data are quoted apart from results of the pressure drop in pipes. However the author encourages the reader to refer to more authoritative works on fluid mechanics, where such data is fully analysed and collated. The author rightly stresses that careful attention should be paid to systems of units but he does not emphasise that it is very bad practice to use mixed in place of rational systems of units. We might have hoped that a textbook on fluid mechanics published by the British press would have pioneered the use of the slug as the unit of mass in the now well established foot-slug-second system of units in which the pound is the unit of force. However whether or not the author intended it, the reader may gain the impression from reading the text that engineers should equally use either the poundal or the pound weight as the unit force. To be conversant with the conversion from one system of units to another is one thing but to find an author switching from one system to another throughout a text book is irritating to say the least. In fact the space afforded to the discussion on the foot-pound-second system of units could with advantage have been used in introducing the M.K.S. system, which surprisingly few engineers seem to be conversant with. (As an example of the mixed treatment of units we note, apart from the printing error on page 7 in which viscosity is quoted in gm. sec.$^{-1}$ ft.$^{-1}$ units, that in the text the gas constant R for air is quoted as $96 \times 32{\cdot}2$ ft.^{2} sec.$^{-2}$ °C^{-1} whereas in the example on page 26 it is quoted as 96 ft. Lb. lb.$^{-1}$ °C^{-1}.) The importance of the use of rationalised systems of units is made very clear to the young engineer when he has to evaluate non-dimensional groups, such as the Reynolds number, when he is given ρ (lb./ft.^{3}), V (ft./sec.), l (ft.) and μ (Lb. sec./ft.^{2}).

Although the present work is well presented and will no doubt make some appeal to the young engineer or undergraduate, it must with regret be pointed out that it is not quite the sound authoritative account of elementary fluid mechanics which it sets out to be and which, as has been stressed already, is so essential. There is hardly space to describe in detail all the misleading statements which appear throughout the book, especially when the author makes excursions into aeronautics. For instance we note that as an example on forces in static fluids the author gives the pressure distribution around an aerofoil in a wind tunnel. We might well ask how the lift force can be determined if the incidence of the aerofoil is not given. Again the author states that the potential flow streamlines around a circular cylinder agree with experiment when the Reynolds number is less than unity, whereas a little thought

will show that viscosity effects are very large, as evidenced by the streamlines in Stokes' flow at still lower values of the Reynolds number. A further example occurs in Chapter 6 on the lift and drag on aerofoils. No statement is made as to whether the aerofoil considered is two-dimensional or is of finite span, so that the use of the momentum equation, in which a control surface is not defined, gives misleading results. This chapter might have been the keystone for the whole book for in it should have been all the basic tools necessary for the " aerodynamic design " of hydraulic axial flow pumps.

The subjects covered by the author are as follows. After chapters on the properties of fluids and elementary hydrostatics, including buoyancy forces and flotation mechanics, there are short chapters on fluid motion definitions and streamline plotting. This is followed by chapters on the forces and pressures in fluids in motion, with applications of Bernoulli's equation. Compressibility effects are dealt with in Chapter 9 (in which entropy is not defined) followed by dimensional analysis and a discussion on secondary flows in curved pipes. Nearly 30 pages are devoted in Chapter 12 to an analysis of the boundary layer followed by the flow in pipes, canals and rivers. Chapter 15 deals with hydraulic machinery, while the final chapter is devoted to unsteady flows in pipes.

In conclusion it should be added that, although there is much that might be criticised in this textbook, it is acknowledged that parts of the book are good and are in keeping with the aims stated by the author in the preface. On the whole the author's style is bold and the text is easy to read. The standard of the format is good and many of the diagrams are excellent. It is to be hoped, however, that in any subsequent editions the author will take steps to modify the text so that it is brought in line with modern thoughts and concepts in fluid mechanics, especially in aerodynamics.—G. M. LILLEY.

FAMOUS BOMBERS OF THE SECOND WORLD WAR. *William Green. Macdonald, London, 1959. Illustrated. 21s.*

A historical record seldom pleases everyone, but William Green's latest work must please most of those who seek information on bombers of the Second World War. A highly concentrated account of the historical development of twelve of the more important bombers used by Allies and Axis might make dull reading, but, provided it is read in reasonable doses, Green has managed to make it quite absorbing. An account of this sort was made necessary by his previous book on fighters. It is understood that second volumes on each subject are due to be published before long. They will be welcome additions to the library. Minor inaccuracies are present in the first edition, but will no doubt be eradicated when the book is reprinted. Great credit is due to the author for his thoroughness. One notes with sympathy his brave attempt to describe the colours of these aircraft. Artistic historians may not always agree with the result, but the author has made a commendable effort.—A.S.C.L.

Additions to the Library

Air Traffic Control. C. D. Colchester. Marconi, Chelmsford. 1960. 100 pp. Illustrated. 17s. 6d. *To be reviewed.*

ARDC Model Atmosphere, The. General Motors Corporation, 1959. 34 pp. No price. Prepared by the Applied Mathematics Section, Missile Department, Allison Division. The calculation of a table of values was programmed for an IBM 704 on the theoretical basis of Report AFCRC TN-56-204 dated December 1956. Values are printed to eight significant digits.

Circular Cylindrical Shells. D. Rüdiger and J. Urban, Leipzig Teubner Verlagsgesellschaft, 1955. 270 pp. 42s. This book from the Eastern zone, is in side-by-side columns of English and German. The sub-title is "A tabular compilation for computing circular cylindrical shell structures of arbitrary dimensions."

Etiology of Postdecompression Shock in Aircrewmen, The. W. L. Rait. 1959. 15 pp. A reprint from the U.S. Armed Forces Medical Journal. The author is with the Royal Australian Air Force. The paper concludes with 45 references.

Exploration of Outer Space, The. A. C. B. Lovell. Royal Society of Arts. 1960. 21 pp. A foolscap preprint of the Trueman Wood Lecture delivered to the Royal Society of Arts by the Director of Jodrell Bank on the 24th February.

Fabrication of Molybdenum. Julius J. Harwood and others. American Society for Metals. Cleveland. 1959. 221 pp. Illustrated. $6.50. Eighteen papers collected by the publishing Society and dealing with all aspects of the working of this metal. Its application to high-temperature work is specially featured and papers deal with its brazing and three methods of welding.

Famous Bombers of the Second World War. William Green. Macdonald, London. 1959. 134 pp. Illustrated. 21s. *Reviewed above.*

Fourth Midwestern Conference on Solid Mechanics 1959. University of Texas, 1959. 530 pp. Illustrated. No price quoted. The 29 papers, by American authors, read at the Conference in September 1959.

Great Aircraft. Norman Macmillan. Bell. 1960. 304 pp. Illustrated. 21s. *To be reviewed.*

Practical Use of Radio Aids for Pilots, The. J. A. Terras. Pitman, London. 1960. 67 pp. Illustrated. 12s. 6d. *To be reviewed.*

Problems of Low Temperature Physics and Thermodynamics. International Institute of Refrigeration. Pergamon, London. 1959. 341 pp. 70s. The proceedings of the meeting of Commission I of the International Institute of Refrigeration, Delft, in 1958. Forty-six papers are given in French or English with abstracts in the other language. One wonders how the editors arrived at the authors of an English paper as Hull, D.; Harwell, A.E.R.E.; and Rosenberg, H. M.

Rocket Propulsion. Marcel Barrère *et al.* Van Nostrand, London. 1960. 829 pp. Illustrated. £6 15s. *To be reviewed.*

Scientific Papers of G. I. Taylor, Vols. I and II. G. K. Batchelor. Cambridge University Press, London. 1958 and 1960. Vol. I, 593 pp. Illustrated. Vol. II, 515 pp. Diagrams. 75s. each. *To be reviewed.*

Sixth Midwestern Conference on Fluid Mechanics 1959. University of Texas, 1959. 465 pp. Illustrated. No price quoted. Thirty papers by American authors.

Space Flight, Vol. I, Environment and Celestial Mechanics. K. A. Ehricke (Principles of Guided Missile Design series). Van Nostrand, London. 1960. 513 pp. Illustrated. £5 9s. *To be reviewed.*

Turbulence. J. O. Hinze. McGraw-Hill, London. 1959. 586 pp. Illustrated. £5 16s. 6d. *To be reviewed.*

Wings over Westminster. T. Lucking (*Editor*). Bow Group. 1960. 95 pp. 7s. 6d. *To be reviewed.*

Reports

AERODYNAMICS

Boundary Layer—*see also* Thermo-Aerodynamics Aircraft Operation

A list of the journals and periodicals to which reference is made in Incompressible Aerodynamics and Laminar Boundary Layers together with their abbreviations. C.P. 444. 1960.

The first two volumes of the Aeronautical Research Council's new series, the *Fluid Motion Memoirs* contain extensive bibliographies. *Incompressible Aerodynamics*, edited by B. Thwaites and published by the Clarendon Press early in 1960, contains over 800 references, and *Laminar Boundary Layers*, edited by L. Rosenhead and due for publication about a year later, contains over 1,000 references. The majority of these references are taken from some 200 journals and periodicals which seem to cover fairly completely the field of incompressible fluid flow. To remove any ambiguities and to assist those who wish to consult the original works, all the abbreviations used are listed, together with the full titles and places of origin.—(1.1.1.1×1.4×30.1).

Some effects of shock-induced separation of turbulent boundary layers in transonic flow past aerofoils. H. H. Pearcey. R. & M. 3108. 1959.

The effects of shock-induced separation of turbulent boundary layers on two-dimensional aerofoils are introduced by considering the development of the surface-pressure distribution and flow pattern as the free-stream speed is increased in the transonic range. The physical nature of the overall flow and the mechanism by which separation affects its development so strongly are described qualitatively. Considerations of the flow at the trailing edge of the aerofoil and downstream along the wake figure prominently in the description and the pressure at the trailing edge position is used extensively. The repercussions which these effects have on the variation of forces and moments are discussed briefly.—(1.1.4.3).

The occurrence and development of boundary-layer separations at high incidences and high speeds. H. H. Pearcey. R. & M. 3109. 1960.

The manner in which the onset of the effects of boundary layer separation varies with Mach number for two-dimensional aerofoils is described, and the influence of section shape as far as it is known is discussed. A brief qualitative description is given of the mechanism underlying the development of the separated flow and its effects, followed by a discussion of some of the ways in which this is likely to differ for swept-back wings at high speeds.—(1.1.4.2× 1.1.4.3×1.1.4.4).

An experimental investigation at a Mach number of 4·95 *of flow in the vicinity of a* 90° *interior corner alined with the free-stream velocity. P. C. Stainback. N.A.S.A. T.N. D-*184. *Feb.* 1960.

An investigation was made to determine the effects of the shock boundary layer interaction on the static pressure and heat transfer rate of an interior corner. The investigation was made at a nominal Mach number of 4·95 and a stagnation temperature of 400° F. —(1.1.2.4×1.9.1).

*A simplified study on the nonequilibrium Couette and boundary layer flows with air injection. P. M. Chung. N.A.S.A. T.N. D-*306. *Feb.* 1960.

A theoretical study is made on the simultaneous effect of the finite recombination rate of oxygen atoms and the fluid injection on the heat transfer to a flat surface. Couette flow and Rayleigh's analogy for laminar boundary layer flow are studied. All the fluid properties except temperature and composition are considered to be constant and a special linear approximation of the homogeneous reaction rate law is made.—(1.1.1.4×1.9.1).

Explorations de la couche limite, en turbulence naturelle et en turbulence provoquée, dans le cas d'un écoulement supersonique le long d'une plaque plane. J. F. Dorand. Pubs. Sc et Tech 355. 1959. *(In French).*

Precise dynamic thermal investigations were made in the transition region of the boundary layer along a flat plate in a supersonic flow at $M=1\cdot85$, both for natural transition and with a transition wire. The precision of the method of exploration showed up certain phenomena which went unnoticed in a less refined experiment.—(1.1.3.4).

Compressible Flow—*see also* Thermo-Aerodynamics

*Correlation formulas and tables of density and some transport properties of equilibrium dissociating air for use in solutions of the boundary-layer equations. N. B. Cohen. N.A.S.A. T.N. D-*194. *Feb.* 1960.

Correlation formulae and tables for density, the product of density and viscosity, Prandtl number, Lewis number, and a diffusion function as functions of enthalpy and pressure are evolved from available property data. These functions are appropriate for calculating real-gas equilibrium boundary layers. The correlations cover a range in pressure from 10^{-4} to 10 atmospheres and an enthalpy range from 128·7 Btu/lb. (corresponding to a temperature of 540° F.) to 16,930 Btu/lb. (corresponding to flight at approximately 29,000 ft./sec).—(1.2.3.1×1.9.1).

*The supersonic boom of a projectile related to drag and volume. I. L. Rhyming. Boeing Doc. D*1-82-0023. *Oct.* 1959.

The Whitham theory predicting the far flow field around a projectile is used to derive body shapes which produce extreme bow shock wave pressure jump or "boom", subject to constraining conditions regarding the drag due to the bow shock and fineness ratio of the bodies.—(1.2.3.2×5.6).

*Supersonic boom of wing-body configurations. L. L. Rhyming and Y. A. Yoler. Boeing Doc. D*1-82-0034. 1960.

The supersonic boom in steady, level flight of a wing-body configuration is due to the effects of body volume, wing volume, wing incidence or lift and wing-body interference. The contribution in the far field of each of these factors can, in any given azimuthal plane be represented as that of an equivalent body of revolution. This concept is developed to investigate the possibilities of using interference among the components of a wing-body configuration to reduce or suppress the boom due to lift. Results of wind tunnel experiments are also presented and discussed in the light of theoretical indications.—(1.2.3.2×5.6).

Controls—*see also* Power Plants

Aerodynamic damping at Mach numbers of 1·3 *and* 1·6 *of a control surface on a two-dimensional wing by the free-oscillation method. W. J. Tuovila and R. W. Hess. N.A.S.A. T.N. D-*116. *Feb.* 1960.

The test results are compared with results calculated by two and three-dimensional oscillating air-force theories.—(1.3.0.1× 1.8.0.2×2×1.10.0.1).

Free-flight investigation at Mach numbers between 0·5 *and* 1·7 *of the zero-lift rolling effectiveness and drag of various surface, spoiler, and jet controls on an* 80° *delta-wing missile. E. D. Schult. N.A.S.A. T.N. D-*205. *Feb.* 1960.

Tests were made of various deflected surfaces, spoilers, and inlet air-jet devices to substantiate simple theory for deflected surfaces, and to determine some effects of chordwise location for spoilers and blowing direction and spanwise location for jets. The fuselage shape was modified for one case.—(1.3.1.2×1.3.1.1×1.3.6×1.3.8).

*An experimental investigation to determine the effect of speed-brake position on the longitudinal stability and trim of a swept-wing fighter airplane. R. T. Taylor. N.A.S.A. T.N. D-*246. *Feb.* 1960.

A 0·10-scale model of a swept-wing fighter aeroplane was tested in the Langley high speed 7×10 ft. tunnel at Mach numbers from 0·60 to 0·92 to determine the effects of adding underfuselage speed brakes. The results of brief spoiler-aileron lateral control tests also are included.—(1.3.4×1.8.2.2).

Fluid Dynamics—*see also* Boundary Layer

Vergleich von Korona-und Hitzdrahtanemometer durch Messung von Turbulenzspektren. B. Franzen et al. *Forsch. des Landes Nordrhein-Westfalen. Nr.* 760. 1959.—*(In German).*—(1.4.2×24×1.12.6).

*A review of magneto-hydrodynamics. Y. A. Yoler. Boeing Doc. D*1-82-0027. *Oct.* 1959.—(1.4.4).

INTERNAL FLOW—*see also* TESTING AND INSTRUMENTS

Experimental investigation of mixing of Mach number 3·95 stream in presence of wall. M. Visich and P. A. Libby. N.A.S.A. T.N. D-247. Feb. 1960.
An experimental investigation of the turbulent mixing of a supersonic stream with a subsonic stream bounded by a wall is described. The Mach number of the main stream was 3·95 while the mass flow of the secondary stream was varied from zero to a value assuring subsonic flow at the origin of mixing.—(1.5.1.1).

LOADS—*see also* AEROELASTICITY

Power spectrum analysis of gust loads on the Comet wing and tailplane. D. T. Jones. C.P. 465. 1960.
An analysis of measurements of normal acceleration and stress, recorded on Comet aircraft while flying in continuous turbulence at high and low altitude, is described. Estimates are given of the amplifying effects due to the resonance.—(1.6.3 × 24).

Vertical-tail loads measured in flight on four airplane configurations at transonic and supersonic speeds. R. D. Reed. N.A.S.A. T.N. D-215. Feb. 1960.
Aerodynamic loads were obtained from the X-5 aeroplane, an F-100 with a small vertical tail, an F-100 with a large vertical tail, and the X-1E aeroplane. Effects of sideslip angle, rudder deflection, and Mach number are presented for trim flight at altitudes from 40,000 ft. to 70,000 ft. and at Mach numbers from 0·70 to 2·08. Comparisons are made with simple theoretical methods of estimating the loads. Also, the total directional stability for each aeroplane as calculated by use of vertical tail loads is shown.—(1.6.1 × 1.8.1.2 × 3.6).

Calculation of aerodynamic loading and twist characteristics of a flexible wing at Mach numbers approaching 1·0 and comparison with experiment. J. P. Mugler. N.A.S.A. T.R. R-58. 1960.
An iteration method is presented by which the detailed aerodynamic loading and twist characteristics of a flexible wing with known elastic properties may be calculated. The method is applicable at Mach numbers approaching 1·0 as well as at subsonic Mach numbers. Calculations were made for a wing-body combination; the wing was swept back 45° and had an aspect ratio of 4. Comparisons were made with experimental results at Mach numbers from 0·80 to 0·98.—(1.6.1 × 2).

STABILITY AND CONTROL—*see also* CONTROLS
LOADS
AEROELASTICITY
EXTRA-ATMOSPHERIC TECHNOLOGY

The rolling moment due to sideslip of swept wings at subsonic and transonic speeds. E. C. Polhamus and W. C. Sleeman. N.A.S.A. T.N. D-209. Feb. 1960.
An analysis has been made of results obtained in a systematic research programme concerned with the effects of wing sweep, aspect ratio, taper ratio, and dihedral on the rolling moment due to sideslip of wing-fuselage configurations up to Mach numbers of about 0·95. New methods have been derived and design charts are presented for estimating the effects of compressibility and wing geometry on the rolling moment due to sideslip.—(1.8.1.2 × 1.10.0.2).

Low-speed investigation of static longitudinal and lateral stability characteristics of an airplane configuration with a highly tapered wing and with several body and tail arrangements. P. G. Fournier. N.A.S.A. T.N. D-217. Jan. 1960.
Results are presented of the static longitudinal and lateral stability characteristics of a low-speed investigation of an aeroplane configuration with a three-body arrangement and a highly tapered wing with its 0·80-chord line unswept and with several tail arrangements as well as a conventional single-fuselage model with the same wing. The wing had a taper ratio of 0, an aspect ratio of 4, and an NACA 65A004 aerofoil section.—(1.8.1.2 × 1.8.2.2).

THERMO-AERODYNAMICS—*see also* BOUNDARY LAYER
COMPRESSIBLE FLOW
TESTING AND INSTRUMENTS
STRUCTURES—THEORY AND ANALYSIS
WEIGHT ANALYSIS AND CONTROL
THERMODYNAMICS

The melting of bodies in a supersonic flow. O. N. Kastelin et al. *R.A.E. Lib. Trans.* 869. 1960.—(1.9.1 × 1.2.3).

An approximate analytical method for studying entry into planetary atmospheres. D. R. Chapman. N.A.S.A. T.R. R-11. 1959.
The complete pair of motion equations for entry into a planet's atmosphere is reduced to an ordinary, nonlinear differential equation of second order by introducing a certain mathematical transformation. This equation includes terms representing the gravity force, centrifugal force, lift force, drag force, and vertical acceleration. Study is made of the decelerations, heating rates, and total heat absorbed for entry into Venus, Earth, Mars and Jupiter.—(1.9.1 × 22.2 × 25.2 × 8.2).

Analysis of turbulent flow and heat transfer on a flat plate at high Mach numbers with variable fluid properties. R. G. Deissler and A. L. Loeffler. N.A.S.A. T.R. R-17. 1959.
A previous analysis of turbulent heat transfer and flow with variable fluid properties in smooth passages is extended to flow over a flat plate at high Mach numbers, and the results are compared with experimental data. Velocity and temperature distributions are calculated for a boundary layer with appreciable effects of frictional heating and external heat transfer. Skin friction and heat transfer coefficients are calculated and compared with incompressible values. The rate of boundary layer growth is obtained for various Mach numbers.—(1.9.1 × 1.2.3.1 × 1.1.3.4).

Aerodynamic-heating data obtained from free-flight tests between Mach numbers of 1 and 5. C. B. Rumsey et al. *N.A.S.A. T.N. D-216. Jan.* 1960.
Aerodynamic heating data were obtained from temperature measurements made at a single station on each of two models. The first model provided data on a parabolic nose between Mach numbers of 2·3 and 5·0. The second model provided data on a conical nose between Mach numbers of 1·1 and 4·0. The measurements are compared with the theory of Van Driest for turbulent flow.—(1.9.1).

WINGS AND AEROFOILS—*see also* CONTROLS
STABILITY AND CONTROL

Drag reduction of thin wings at supersonic speeds, by the use of camber and twist. G. M. Roper. R. & M. 3132. 1959.
Camber and twist is applied to the problem of reducing the drag due to incidence, of thin triangular or swept-back wings, at supersonic speeds, with subsonic leading edges and supersonic or sonic trailing edges. Two cases are considered: with leading edge suction forces ignored: with leading edge suction forces included.—(1.10.1.2).

HELICOPTER AERODYNAMICS

Static-stability measurements of a stand-on type helicopter with rigid blades, including a comparison with theory. G. E. Sweet. N.A.S.A. T.N. D-189. Feb. 1960.
Results of an investigation in low-speed forward flight are presented. The results include measurements of forces and moments and static-stability derivatives determined from these measurements. Pitching moments and static stability derivatives for the isolated rotors, as deduced from the measurements, are compared with rigid rotor theory.—(1.11.2 × 29.1).

TESTING AND INSTRUMENTS—*see also* FLUID DYNAMICS
AIRCRAFT OPERATION
SCIENCE—GENERAL

Boundary-induced downwash due to lift in a two-dimensional slotted wind tunnel. S. Katzoff and R. L. Barger. N.A.S.A. T.R. R-25. 1959.
A solution has been obtained for the complete tunnel interference flow for a lifting vortex in a two-dimensional slotted tunnel. Curves are presented for the longitudinal distribution of tunnel-induced downwash angle for various values of the boundary openness parameter and for various heights of the vortex above the tunnel centre line. Some quantitative discussion is given of the use of these results in calculating the tunnel interference for three-dimensional wings in rectangular tunnels with closed side walls and slotted top and bottom.—(1.12.1.1 × 1.5.1.4).

A high-velocity gun employing a shock-compressed light gas. C. Bioletti and B. E. Cunningham. N.A.S.A. T.N. D-307. Feb. 1960.
Projectiles of 20 mm. diameter are launched by helium which has been compressed and heated by a two-stage shock process. An explosion of powder is the source of energy. The unusual feature is a light piston which operates at supersonic speed in the second-stage shock tube. Muzzle velocities of over 20,000 ft./sec. are obtained with light projectiles.—(1.12.2 × 1.9 × 25.2).

Performance studies for the University of Southampton hypersonic gun tunnel. K. N. C. Bray et al. *U.S.A.A. Report* 103. *April* 1959.
A brief description of the tunnel is given and its mode of operation is outlined. Results are presented of performance calculations which are divided into three stages: the piston motion, the shock reflection process and the expansion through the nozzle. From these calculations the range of operating conditions which should be obtainable in the tunnel is deduced. Preliminary results are presented of a few experiments to check the assumptions which have been made in these calculations.—(1.12.1.3).

An investigation of the model blockage for wind tunnels at Mach numbers 1·5 *to* 19·5. *C. J. Schueler. A.E.D.C. T.N.*-59-165. *Feb.* 1960.
An experimental investigation of the test section flow blockage characteristics was conducted in the 12×12 in. supersonic wind tunnel of the von Karman Gas Dynamics Facility, Arnold Engineering Development Centre. The purpose of the tests was to determine whether a method of predicting the maximum size model which will permit the establishment of supersonic flow, based on the model frontal area and bow shock-wave strength, is applicable over a wide range of Mach numbers. The tests were conducted using test models consisting of 15, 20 and 28° half-angle cones. Permissible hemisphere-cylinder model sizes from several wind tunnels covering the Mach number range from 1·5 to 19·5 are also presented.—(1.12.1.3×1.5.1.4).

"Morgandyne" heat-transfer transducer and a flame-torch calibration technique for hyper-velocity wind tunnels. C. C. Morgan and J. C. Andrews. A.E.D.C. T.R.-60-1. *Feb.* 1960.
The transducers and related calibration equipment, used to measure the transient heat transfer rates in the arc-heated Hotshot hypervelocity wind tunnels at A.E.D.C., are described. Thermistor and thin film gauges are described briefly, and a variable reluctance Morgandyne gauge is covered in detail. Water jet and oxy-acetylene torch equipment for the calibration and transient heat transfer gauges is described. The torch calibration system has been developed for heat transfer rates from 90 to 400 Btu/ft.²sec.—(1.12.6×1.12.1.3×1.9.1).

AEROELASTICITY

See also AERODYNAMICS—CONTROLS
LOADS
FLIGHT TESTING

A method for calculating the aerodynamic forces due to arbitrary, time-dependent downwash for a class of thin, flexible wings at supersonic speeds. R. W. Warner and B. P. Packard. N.A.S.A. T.N. D-142. *Feb.* 1960.
The plan forms, which must have every edge everywhere supersonic, are divided into a number of discrete areas, or boxes, of uniform downwash. These boxes are used to define indicial aerodynamic influence coefficients.—(2×1.6.3×1.8.2.2).

AIRCRAFT

See AERODYNAMICS—LOADS
HYDRODYNAMICS
POWER PLANTS

DESIGN AND CONSTRUCTION

See STRUCTURES—LOADS

AIRCRAFT OPERATION

See also AERODYNAMICS—COMPRESSIBLE FLOW
METEOROLOGY

Adsorption of halogenated fire extinguishing agents on powders. A. J. Barduhn et al. *N.A.S.A. T.R. R*-51. 1960.
The amounts of four different Freons adsorbed by carbon, silica gel, alumina and molecular sieves were determined at pressures up to 225 lb./in.² Several adsorbed systems were tested in a standard dry-power extinguisher on a 5 ft.² gasoline fire for their effectiveness in putting out a fire.—(5.3×21.3).

Effects of flight simulator motion on pilots' performance of tracking tasks. J. G. Douvillier et al. *N.A.S.A. T.N. D*-143. *Feb.* 1960.
The effect of rolling and pitching motion of a flight simulator on pilot's performance of a simulated tracking task was estimated from comparisons of experimental results among flight, and motionless and moving simulators. Also, a comparison between two different radar tracking displays was obtained from the flight tests.—(5×1.12.6).

Boundary layer noise research in the U.S.A. and Canada; a critical review. E. J. Richards et al. *U.S.A.A. Report* 131. *Feb.* 1960.
A resume of experimental and theoretical boundary layer noise research in the U.S.A. and a collection of existing experimental data are given.—(5.6×1.1.3).

AIRPORTS

See STRUCTURES—LOADS

EXTRA-ATMOSPHERIC TECHNOLOGY

See also AERODYNAMICS—THERMO-AERODYNAMICS
MISSILES

A study of the guidance of a space vehicle returning to a braking ellipse about the earth. J. A. White. N.A.S.A. T.N. D-191. *Jan.* 1960.
A study has been made to determine the most efficient method of scheduling and applying corrective impulses along the trajectory of a space vehicle returning to a braking ellipse about the earth. The Monte Carlo technique was used to study the relative performance of three methods of scheduling corrective thrust impulses in the presence of various assumed inaccuracies in measuring velocity and flight-path angle and in obtaining the desired thrust impulse.—(8.2×25.1).

ELECTRONICS

A radar test target system. J. T. Rose and R. D. Smith. N.A.S.A. T.N. D-164. *Jan.* 1960.
Descriptions of two versions of a radar test target system are presented. Included is a description of a low radar signal reflecting plastic rocket used as a third-stage vehicle on one of the versions of the system. Also included are the results from all preflight and flight tests of the system.—(11×27.3×25.2).

The theory and design of a clamped-diaphragm, composite-dielectric, variable-capacitance transducer. K. Posel. Univ. Witwatersrand. Dept. Mech. Eng. Report 1/59. *Dec.* 1959.
Despite the widespread use of the clamped diaphragm, composite-dielectric variable-capacitance transducer for many years, the literature on its design is meagre, and in many instances also unfortunately incorrect. A new set of design equations for the transducer are derived, and experimental verification is provided.—(11).

FLIGHT TESTING

See also POWER PLANTS

An electrodynamic method of exciting servo-tabs for flight flutter testing. W. H. Johnson. C.P. 466. 1960.
A detailed description is given of an electrodynamic method of exciting servo-tabs for flight flutter testing. Tests made to develop and establish the feasability of the technique on a large aircraft with pure servo-tab controls are described. Some specimen flight records are shown.—(13×2).

FUELS AND LUBRICANTS

See POWER PLANTS

HYDRODYNAMICS

Hydrodynamic characteristics of a planing surface with convex longitudinal curvature and an angle of dead rise of 20°. *E. J. Mottard. N.A.S.A. T.N. D*-180. *Jan.* 1960.
Wetted length, resistance, and c.p. location were determined for a radius of curvature of 20 beams, beam-load coefficient from -3 to 37, Froude numbers from 6 to 25, and Reynolds numbers from 5×10^5 to 10^7.—(17.2).

*Experimental investigation of aspect-ratio-*1 *supercavitating hydrofoils at speeds up to* 185 *feet per second. K. W. Christopher and V. E. Johnson. N.A.S.A. T.N. D*-187. *Jan.* 1960.
Two hydrofoils (one flat-bottomed and one cambered) of aspect ratio unity have been tested at both zero cavitation number and low finite cavitation numbers. The tests were made over a range of depths of submersion from 0 to approximately 1 chord and of angles of attack from 3° to 20°.—(17.2×17.1).

Hydrodynamic impact-loads investigation of chine-immersed 0° *dead-rise configurations having longitudinal curvature; with an appended bibliography of Langley impact basin hydrodynamic publications. R. W. Miller. N.A.S.A. T.N. D*-207. *Feb.* 1960.
Impact load data are presented for two narrow-beam configurations:

one having the forward half curved upward, the other having the same curvature over the rear half. Impacts were made at fixed trim in smooth water at beam loading coefficients of about 18, 29, and 36 and over a range of landing-approach conditions.—(17.2).

A brief investigation of a hydro-ski stabilized hydrofoil system on a model of a twin-engine amphibian. S. M. Stubbs and E. L. Hoffman. N.A.S.A. T.N. D-220. Feb. 1960.
A hydrodynamic investigation of a supercavitating hydrofoil system mounted on a ¼-size powered dynamic model of a twin-engine amphibian was conducted in the Langley towing tanks. The investigation was made to determine some of the resistance characteristics during take-off and stability characteristics during take-off and landing.—(17.2×3.10).

MATERIALS

See also AIRCRAFT OPERATION
POWER PLANTS
FATIGUE
STRUCTURES—LOADS
WEIGHT ANALYSIS AND CONTROL

Fatigue tests on notched extruded aluminium alloy (DTD 364B) having a theoretical stress concentration factor of 3·65. *W. A. P. Fisher. C.P.* 460. 1960.
Fatigue tests were made in axial tension at ratios of mean to alternating stress of 1·1, 2 and 3, and at fixed mean stresses of 8,800, 14,000 and 18,000 lb./in.² The tests provide data on the fatigue of alloy to DTD 364B (now L65) with a comparatively high stress concentration and also on the notch sensitivity of this material.—(21.2.2×31.2.2.3.2.1.1).

Thermal degradation of certain polymers under oxidative conditions. D. B. V. Parker. C.P. 464. 1960.
The rate of loss of weight of a powdered polymer when heated in air was taken as an inverse measure of thermal stability under oxidative conditions. A number of other polymers and plastic materials were examined using the same technique.—(21.3).

Graphite as a structural material in conditions of high thermal flux. A. J. Kennedy. CoA Report 121. *Nov.* 1959
The state of fundamental knowledge on the subject of graphite and the graphitisation process is reviewed. The present state of development of the four principle methods of manufacture is examined. Considerations relating to thermal shock, creep and fabrication are surveyed.—(21.2.2).

Exploratory investigation of several coated and uncoated metal, refractory, and graphite models in a 3,800° F. *stagnation temperature air jet. O. F. Trout. N.A.S.A. T.N. D-*190. *Feb.* 1960.
Hot air jet tests were made on various coated and uncoated metal, refractory and graphite models. A description of the tests and the results are provided.—(21.2.2×21.3.1×21.4).

Tension, compression, and fatigue properties of several SAE 52100 *and tool steels used for ball bearings. G. Sachs* et al. *N.A.S.A. T.N. D-*239. *Feb.* 1960.
The room temperature elastic limit, yield strength, and ultimate strength in tension, the elastic limit and yield strength in compression, and S-N curves at cycles up to 100 million for several vacuum-melted steels used for high-temperature bearings were compared with those of the common SAE 52100 bearing steel. Tests were conducted at 350° and 500° F.—(21.2.1×31.2.2.2.2.1).

Continued study of advanced-temperature nickel-base alloys to investigate vanadium additives. J. C. Freche et al. *N.A.S.A. T.N. D-*260. *Feb.* 1960.
An investigation was conducted to extend the useful temperature range of a series of previously developed advanced-temperature nickel-base alloys that do not require vacuum-melting techniques.—(21.2.2).

Uranium dioxide compatibility with refractory metals, carbides, borides, nitrides, and oxides between 3,500° *and* 5,000° *F. J. J. Gangler* et al. *N.A.S.A. T.N. D-*262. *Feb.* 1960.
The compatibility of uranium dioxide with 30 refractory materials was determined in vacuum or in argon for test times of 10 minutes and for test temperatures in the 3,500° to 5,000° F. range.—(21.3.1).

*Predicted behaviour of rapidly heated metals in compression. E. Z. Stowell and G. J. Heimerl. N.A.S.A. T.R. R-*59. 1960.
A phenomenological relation previously proposed for a metal in tension at elevated temperatures is applied to compression under rapid heating conditions. Predictions are made of the behaviour of 7075-T6 aluminium alloy sheet in compression under unrestrained constant-stress conditions and under completely restrained conditions for rates from 0·1 to 100° F./sec.—(21.2.2).

MATHEMATICS

See also AERODYNAMICS—THERMO-AERODYNAMICS

Non-linear vibrations with two degrees of freedom. C. Schmieden. R.A.E. Lib. Trans. 863. *Jan.* 1960.
A double pendulum system with equal lengths but varying mass ratio is studied. The generalisation of Duffing's differential equation for two degrees of freedom is described. The periodic solution for finite amplitude is deduced, and the case studied in which the frequencies of the fundamental and overtone vibrations are in an integral ratio.—(22.2).

*Nodal expansions. III. Exact integral equations for particle correlation functions. E. Meeron. Boeing Doc. D*1-82-0041. *Jan.* 1960.
The density expansions of the pair distribution function and potential of average force are analysed topologically in terms of cutting points and bifocal points.—(22.1).

*Topological methods in the cluster theory of ionic solutions. E. Meeron. Boeing Doc. D*1-82-0036. *Dec.* 1959.
The two methods most often used in the theoretical evaluation of radial distribution functions and potentials of average force in ionic solutions are solutions of certain integral equations and expansions in powers of ion number densities.—(22.1).

METEOROLOGY

See also AERODYNAMICS—FLUID DYNAMICS
LOADS
SCIENCE—GENERAL

Atmospheric turbulence encountered by Viscount aircraft over Europe. J. R. Heath-Smith. C.P. 463. 1960.
Counting Accelerometer records were obtained from Viscount aircraft during 600,000 miles flying on European routes.—(24).

Summary of rawinsonde measurements of temperatures, pressure heights, and winds above 50,000 *feet along a flight-test range in the southwestern United States. T. J. Larson and H. P. Washington. N.A.S.A. T.N. D-*192. *Jan.* 1960.
Yearly, seasonal, diurnal, and 24-hour variations of temperatures, pressure heights, and winds in the 100-millibar to 2-millibar pressure range from rawinsonde data of four stations along a flight test range in the south-western United States are presented. This range, referred to as High Range, extends from Edwards, Calif., to Wendover, Utah, to accommodate flight operations of the X-15 and other high-performance craft. Comparisons of average temperatures and pressure heights are made with those of the U.S. Extension to the ICAO Standard Atmosphere.—(24×5).

MISSILES

See also AERODYNAMICS—THERMO-AERODYNAMICS
TESTING AND INSTRUMENTS
EXTRA-ATMOSPHERIC TECHNOLOGY
ELECTRONICS
STRUCTURES—THEORY AND ANALYSIS

A method of investigating the ionosphere by means of an artificia earth satellite. K. I. Gringauz. R.A.E. Lib. Trans. 781*A. Jan.* 1960.
In the article published in Progress of Physical Science by Ya. L. Al'pert there are a number of assumptions which relate both to the general physical concepts and to the essence of the suggested method of investigation, and also many formulae which call for a rejoinder. Views on this matter are given.—(25×8).

Static stability and separation characteristics of a two-stage rocket configuration at Mach numbers from 1·57 *to* 4·50. *K. L. Turner* et al. *N.A.S.A. T.N. D-*188. *Jan.* 1960.
The subject investigation was conducted in the Langley Unitary Plan wind tunnel. Each stage of the two-stage rocket configuration is a body of revolution with a length-diameter ratio of approximately 8. Model configurations tested include each stage separately and combined, and the stages being systematically separated from each other.—(25.1×1.8.2.2).

*Requirements of trajectory corrective impulses during the approach phase of an interplanetary mission. A. L. Friedlander and D. P. Harry. N.A.S.A. T.N. D-*255. *Jan.* 1960.
An analysis of the minimum velocity impulse required to correct off-course trajectories is presented, the target being defined in terms of the perigee distance.—(25.1×8.1).

Theorem of image trajectories in the Earth-Moon space. A. Miele. Boeing Doc. D1-82-0039. Jan. 1960.
The motion of a small vehicle in the Earth-Moon space is considered under several hypotheses relative to the behaviour of the Earth-Moon System. It is assumed that the vehicle is subject to the attractions of the Earth, the Moon, and the Sun; that the gravitational fields of the Earth and the Moon obey the inverse square law; and that the gravitational field of the Sun in the neighbourhood of the Earth-Moon system is parallel and uniform.—(25.2×8.1).

POWER PLANTS

See also ELECTRONICS
THERMODYNAMICS

Thermodynamic data for the calculation of gas turbine performance. D. Fielding and J. E. C. Topps. R. & M. 3099. 1954.—(27.1×34.1.1).

Measurement of distortion in second experimental control rod with temperature patterns simulating shim rod out and shim rod 50 per cent inserted for Argonne naval reactor. A. F. Lietzke and T. F. Nagey. N.A.C.A. R.M. E51E25. TIL 6606. *Sept.* 1951.
Thermal distortion tests were made on a stainless steel clad, cadmium-silver control rod. Two temperature patterns were simulated; one represented the shim-rod-out condition and the other the shim-rod 50 per cent inserted condition.—(27.6×21.2).

Calculated performance of nuclear turbo-jet powered airplane at flight Mach number of 0·9. *R. B. Doyle. N.A.C.A. R.M. E50B23. TIL* 6607. *May* 1950.
An analysis was made at flight Mach number of 0·9 to estimate performance of nuclear energy powered turbo-jet engine and optimum engine operating conditions and to determine gross weight and load-carrying capacity of aeroplane powered by such an engine.—(27.1×27.6).

Analysis of the transient radiation heat transfer of an uncooled rocket engine operating outside earth's atmosphere. W. H. Robbins. N.A.S.A. T.N. D-62. Dec. 1959.
The cooling characteristics of a heated body in space are analysed. The results of the analysis are applied to an uncooled rocket engine operating in space. The information required to compute the cooling time is presented for a range of thrusts and running times.—(27.3×34.3.4).

Blowoff of propane and hydrogen diffusion flames at high Mach number, ramjet conditions. R. J. Bacigalupi and E. A. Lezberg. N.A.S.A. T.N. D-67. Dec. 1959.
Blowoff conditions are presented for hydrogen and propane diffusion flames stabilised in the wake of cylindrical fuel injectors. The effect of varying pressure, temperature, and air and fuel flows was determined for several fuel-orifice and tube diameters.—(27.4×34.1.1).

The hydrogen-peroxide rocket reaction-control system for the X-1B research airplane. J. E. Love and W. H. Stillwell. N.A.S.A. T.N. D-185. Dec. 1959.
A fixed thrust on-off H_2O_2-rocket reaction control system was installed in the X-1B research aeroplane as a means of control at high altitude. The design considerations, fabrication, installation, and ground testing of this system are described. The operational characteristics and some problems associated with system operations are discussed.—(27.3×1.3.6×3.6).

Experimental investigation in an altitude test facility of burning of excess combustibles in a rocket engine exhaust. H. E. Bloomer et al. *N.A.S.A. T.N. D-200. Jan.* 1960.
An investigation was made in an altitude test chamber to determine methods of burning the excess fuel in the exhaust of a rocket engine which used JP-4 fuel and gaseous oxygen as propellants.—(27.3×14×34.1.1).

Performance investigation of a nonpumping rocket-ejector system for altitude simulation. A. Fortini. N.A.S.A. T.N. D-257. Dec. 1959.
In the experimental investigation, high pressure nitrogen gas flowed from a convergent-divergent nozzle of area ratio 9 into a cylindrical ejector tube. Variables studied were ejector tube to nozzle-throat area ratios ranging from 16 to 49 and ejector-tube length-to-diameter ratios from 2·67 to 12·0; overall pumping-fluid pressure ratios ranged from 3 to 44. A theory employing nonviscous fluid mechanics was developed.—(27.8×13.3).

Powerplants for VTOL aircraft: A proposed dual-operation system using wing-immersed fans for vertical thrust. E. P. Cockshutt and N. Galitzine. N.R.C. Report LR-265. Oct. 1959.
Calculated performance and weight data are presented for a category of VTOL power plants in which highly loaded fans (500 lb./ft.^{2}), immersed in the wings, are used to augment the hovering thrust of conventional turbo-jet engines.—(27.1×13.3).

Mécanisme de la déviation des jets propulsifs. M. Kadosch. Pubs Sc et Tech B.S.T. 124. 1959. (*In French*).
Theory and experimental results are given of jet deflection by a solid deflector screen, by a fluid screen and by adherance to a curved surface. These deflections are much increased by a combination of two methods. The increase, dependent on scale effect, means that thrust reversal can be achieved. Experimental results and theory of thrust reversal processes are described in detail.—(27.1.1).

Nomographisches Verfahren zur Berechnung von Staustrahltriebwerken. O. Lutz et al. *DFL Bericht* 113. 1959. (*In German*)—(27.1.1).

PROPELLERS

See also AERODYNAMICS—HELICOPTER AERODYNAMICS

Doublet d'hélices coaxiales hélice unique. J. Cristescu. Pubs. Sc. et Tech. 356. 1959. (*In French*).—(29).

REFERENCE LITERATURE

See AERODYNAMICS—BOUNDARY LAYER

FATIGUE

See also MATERIALS

An investigation of nonpropagating fatigue cracks. A. J. McEvily and W. Illg. N.A.S.A. T.N. D-208. Dec. 1959.
Through consideration of the stresses existing at the tip of a fatigue crack an attempt is made to account for nonpropagating fatigue cracks. It is concluded that such cracks may form under constant-amplitude cyclic loading if the crack closes during compression or if the effective radius of the crack is larger than that of the initial notch.—(31.2.2.1.6×33.1.2).

Rotating-beam fatigue tests of notched and unnotched 7075-T6 aluminum-alloy specimens under stresses of constant and varying amplitudes. H. F. Hardrath et al. *N.A.S.A. T.N. D-210. Dec.* 1959.
Unnotched and notched rotating-beam specimens made of 7075-T6 aluminium alloy were tested under constant and varying stress amplitude.—(31.2.2.3.2×21.2.2×33.1.2).

Axial-load fatigue tests of 2024-T3 and 7075-T6 aluminum-alloy sheet specimens under constant and variable-amplitude loads. E. C. Naumann et al. *N.A.S.A. T.N. D-212. Dec.* 1959.
Sheet specimens with a theoretical elastic stress concentration factor of 4·0 were tested with the load amplitude held constant or varied by steps to approximate a gust loads history. The test data were analysed assuming linear cumulative damage, and a limited statistical evaluation was used to confirm conclusions.—(31.2.2.3. 2.1×21.2.2×33.1.2).

Fatigue damage during complex stress histories. H. W. Liu and H. T. Corten. N.A.S.A. T.N. D-256. Nov. 1959.
The relation between fatigue life and the relative number and amplitude of imposed cycles of stress was determined in wire specimens of 2024-T4 and 7075-T6 aluminium alloys and hard drawn steel.—(31.2.2.2.2.1.2×31.2.2.3.2.1.2×21.2).

SCIENCE—GENERAL

The design and use of interferometers in aerodynamics. L. H. Tanner. R. & M. 3131. 1959.
A practical account of the problems, which are encountered in the design and use of interferometers in wind tunnels and shock tubes, and in the analysis and interpretation of interferograms, is given. Topics covered include the design of frame and suspension, mirror mounts and adjustments, the choice of adjustable mirrors and the effects of passing the compensating beam through the tunnel or outside it. An account of the range, sensitivity and relative merits of the Mach-Zehnder and Twyman-Green interferometers is given. A section on factors affecting accuracy deals with temperature changes and stress in the windows, convection currents and

vibration, side-wall boundary layers, unsteady flow and loss of total pressure through shock waves and in dead-air regions. Descriptions of the interferometer which is used on the 9 in. × 3 in. High Speed Wind Tunnel at the N.P.L., and of a larger instrument which is being made, are given.—(32.2.4 × 1.12).

Nèbulogranulométre pour l'étude des brouillards naturels et artificiels. A. Arnulf et al. Pubs Sc et Tech. N.T. 86. (1959). (*In French*).—(32.2.4 × 24).

STRUCTURES

LOADS—*see also* FATIGUE
THEORY AND ANALYSIS

Braking and landing tests on some new types of airplane landing mats and membranes. S. A. Batterson. N.A.S.A. T.N. D-154. *Oct.* 1959.
An experimental investigation was made at the Langley landing-loads track to obtain friction coefficients developed during braking and landing on various types of metal landing mats and prefabricated membranes. The tests were made at forward speeds of about 85 knots with static vertical loads of 20,405 and 13,020 pounds.—(33.1.2 × 6.1).

Dynamic model investigation of a landing-gear configuration consisting of a single main skid and a nose wheel. S. Faber. N.A.S.A. T.N. D-213. *Feb.* 1960.
Variations in nose-wheel shimmy damping and in nose-wheel skid geometry were investigated to determine their effect on directional stability during the landing ground run.—(33.1.2 × 4.2.2.3).

A preliminary investigation of the penetration of slender metal rods in thick metal targets. J. L. Summers and W. R. Niehaus. N.A.S.A. T.N. D-137. *Dec.* 1959.
Slender steel and tungsten-carbide rods were fired into targets of copper, lead, and steel at impact velocities to about 11,000 ft./sec.—(33.1.2 × 21.2).

The effect of a damping compound on jet-efflux excited vibrations. Part 1: *The structural damping due to the compound. D. J. Mead. U.S.A.A. Report* 123. *June* 1959.
The theory is presented of the increase in damping that can be obtained when a damping compound is added to a simple structure vibrating in a bending mode. A preliminary experimental investigation is described, in which damping measurements were made on a simple structural specimen treated with Aquaplas (K.102). A new method was used successfully to determine the damping ratio of a heavily damped system. The damping properties of Aquaplas were evaluated, and some of the theoretical conclusions were verified.—(33.1.2 × 33.2.4.1.10).

THEORY AND ANALYSIS—*see also* LOADS

Principles of design of dynamically similar models for large propellant tanks. P. E. Sandorff. N.A.S.A. T.N. D-99. *Jan.* 1960.
A study is made of the similitude conditions existing between a full-scale propellant tank such as would be used for a large rocket vehicle and a dynamically similar, reduced scale model. Permutations of different design combinations for the model are examined to determine their suitability and practicability.—(33.2.4.3 × 33.1.2).

The influence of aerodynamic heating on the structural design of aircraft. M. W. Rubesin. AGARD Report 207. *Oct.* 1959.
Examples of ways to recover a data capsule from a satellite are discussed. The re-entry vehicles containing the data capsule include lifting as well as non-lifting aircraft.—(33.2.3.0.9 × 1.9.1 × 34.3 × 25).

Déformations irréversibles et résistances mécaniques des joints collés. L. Duossin et A. Popoff. O.N.E.R.A. NT 56. 1960. (*In French*).—(33.2.4.13).

Einfluss der Lage des Lastangriffspunktes auf die Kippstabilität eines gabelgelagerten einfachen Balkens mit doppelt-oder einfachsymmetrischen Querschnitt, der durch eine Einzelkraft in Balkenmitte belastet ist. G. Levin. D.F.L. Bericht 102. 1959. (*In German*).—(33.2.4.1).

Results of stress and deflection measurements performed on a sweptback box beam and their comparison with theoretical results. H. J. v Grol et al. *N.L.L.-T.N. S.*536. *Jan.* 1959.
Stress and deflection measurements performed on a symmetrical swept-back box beam were compared with theoretical results, determined previously by means of the principle of minimum complementary energy and by means of the principle of minimum potential energy. The stress distribution in the spar webs near the root is given in a supplementary analysis. The agreement between the test results and calculations is satisfactory, especially if the latter are based on the principle of minimum complementary energy.—(33.2.3.2).

WEIGHT ANALYSIS AND CONTROL

Optimum design of insulated tension members subjected to aerodynamic heating. J. R. Davidson. N.A.S.A. T.N. D-117. *Dec.* 1959.
A general method for determining the weight efficiency of insulated heat-sink structures is developed by which the lightest total structural weight may be found for any selected insulating and load-carrying materials in terms of a load parameter which accounts for the load, insulation material, and flight time. Charts are presented for six materials which show the comparative efficiency of each material as a function of the load parameter and the temperature of the aerodynamically heated side of the insulation.—(33.4 × 1.9.1 × 21).

THERMODYNAMICS

See also POWER PLANTS
STRUCTURES—THEORY AND ANALYSIS

A method of computing the transient temperature of thick walls from arbitrary variation of adibatic-wall temperature and heat-transfer coefficient. P. R. Hill. N.A.C.A. Report 1372. 1958.
Formulae to determine the transient temperature of thick walls with an arbitrary time variation of adiabatic wall temperature and heat transfer coefficient are presented. The special cases of the thin wall and the infinitely thick wall are also discussed. A simple formula for determining the heat flow from a known temperature history is also given. Heat transfer in a direction parallel to the surface is assumed to be negligible and constant wall properties are assumed.—(34.3).

Spectrographic temperature measurements in a carbon-arc-powered air jet. D. H. Greenshields. N.A.S.A. T.N. D-169. *Dec.* 1959.
A spectrographic method of measuring the free-stream temperature of an electric-arc-powered air jet in the range 3,700° K to 5,400° K has been developed. The method utilises the band radiation of the cyanogen molecule, and depends upon the rotational energies of this species.—(34.2 × 34.1).

Analysis of temperature distribution and radiant heat transfer along a rectangular fin of constant thickness. S. Lieblein. N.A.S.A. T.N. D-196. *Nov.* 1959.
A theoretical analysis is conducted of the steady state radiant heat transfer characteristics of rectangular fin plates of constant thickness with uniform heat source along the leading edge and no convection. Calculations of the variation of temperature and radiating effectiveness with distance from the heat source are made for infinite and finite-length plates over a wide range of ratios of sink-to-source temperatures. Design parameters for minimising plate volume are derived, and application of results to practical radiator considerations is indicated.—(34.3.1).

Chemical sampling downstream of lean, flat hydrogen and propane flames. B. D. Fine. N.A.S.A. T.N. D-198. *Dec.* 1959.
Decay profiles were obtained for carbon monoxide and hydrogen downstream of lean, flat propane-oxygen and hydrogen-oxygen flames. Slopes of decay profiles, obtained as a function of pressure, flame temperature, and burned gas composition, were related to time decay rates in the burned gas.—(34.1.1).

Experimental and analytical investigation of heat-transfer characteristics of a return-flow air-cooled turbine rotor blade. F. S. Stepka and R. P. Cochran. N.A.S.A. T.N. D-202. *Dec.* 1959.
Comparisons of analytically determined and experimentally obtained blade metal and cooling air temperatures through a return-flow blade were made to verify the method and assumptions of the analysis.—(34.3.4 × 27.1).

Tables of thermodynamic properties of air including dissociation and ionization from 1,500° *K to* 15,000° *K. J. Hilsenrath* et al. *A.E.D.C.-T.R.*-59-20. *Dec.* 1959.—(34.1).

The effect of dissociation and recombination of oxygen and nitrogen on the heat transfer to a body flying in a rarefied atmosphere. J. A. Wilson. U.S.A.A. Report 113. *Jan.* 1960.
The object was to determine what effect dissociation or recombination had on the heat transfer rate to a body flying at high velocity in an atmosphere sufficiently rarefied for the equations of free-molecule flow to be valid. The particular case of a circular cylinder was considered.—(34.3 × 1.9.1).